Assessment of Water Quality Trends for the North Bosque River through 2011

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Introduction

This report is an interim update of water quality trends in the North Bosque River watershed assessing the effectiveness of nonpoint source (NPS) and point source control measures associated with the North Bosque Total Maximum Daily Load (TMDL) Implementation Plan (I-Plan). This report largely follows the format of previous annual reports produced for other projects (e.g., McFarland and Millican, 2011) with information updated as appropriate. Trend analyses focus on eight monitoring stations, five of which are index stations (17226 [BO020], 11963 [BO040], 18003 [BO083], 11956 [BO090], and 11954 [BO095]) for the phosphorus TMDLs along the North Bosque River (Figure 1). Station 11926 (BO070) is included as a reference station, while stations 13486 (GC100) and 11961 (NC060) are included to assess the impact of phosphorus control practices within particular areas of the watershed. This report also provides a provisional update on the location of concentrated animal feeding operations (CAFOs) and associated waste application fields (WAFs) within the watershed.

The TCEQ adopted two TMDLs for soluble reactive phosphorus[1] (SRP) for North Bosque River Segments 1226 and 1255 in February 2001 that USEPA approved in December 2001 (TNRCC, 2001). The goal of these TMDLs is an overall reduction of about 50 percent in SRP loadings and concentrations within the North Bosque River, although actual reduction goals vary along the river reach. The I-Plan for these TMDLs was approved by TCEQ in late 2002 and by the Texas State Soil and Water Conservation Board (TSSWCB) in early 2003 (TCEQ and TSSWCB, 2002).

The I-Plan outlines a number of programs to reduce SRP in the North Bosque River. These programs include four basic elements for phosphorus control:

1. Use of phosphorus application rates for land application of dairy manure,
2. Use of reduced phosphorus in diets of dairy cows to decrease manure phosphorus,
3. Removal of about half the dairy-generated manure from the watershed, and
4. Implementation of phosphorus effluent limits on municipal wastewater treatment plants (WWTPs).

To address phosphorus application rates on dairy WAFs, the TSSWCB initiated the Comprehensive Nutrient Management Plan (CNMP) Program. The TSSWCB supports the voluntary implementation of CNMPs by dairy producers as part of their water quality management plans (WQMPs) for animal feeding operations (AFOs). In addition to voluntary compliance, the TCEQ amended rules[2] for concentrated animal feeding operations (CAFOs) in 2004 to require permitted dairies in the North Bosque to implement Nutrient Management Plans (NMPs).

[1] Soluble reactive phosphorus is commonly referred to as orthophosphate phosphorus (PO_4-P).
[2] Subchapter B Concentrated Animal Feeding Operations, Chapter 321, Texas Administrative Code Title 30, §321.31 – §321.27.

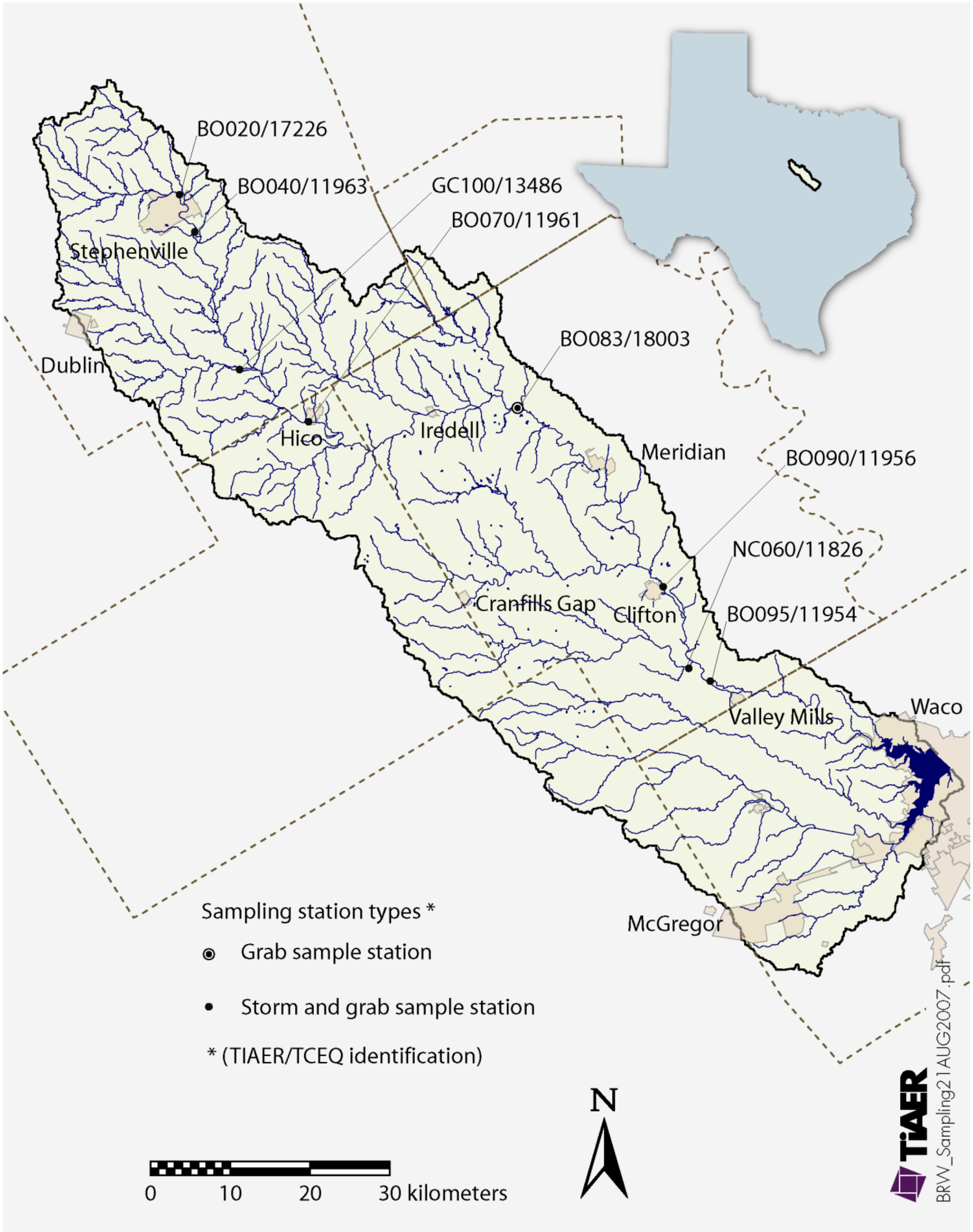

Figure 1 North Bosque River watershed trend analysis monitoring stations

A NMP addresses nutrient management guidance for cropping systems as part of a conservation plan for producers and landowners. A CNMP encompasses most aspects of a nutrient management plan (NMP), but additionally may include specifications for feed management, manure and wastewater handling and storage, nutrient management, land treatment practices, and other manure and wastewater utilization options addressing the overall agronomic and environmental aspects of an animal feeding operation (TCEQ and TSSWCB, 2002). The adoption of CNMPs, and, thus, NMPs, has been slow, but in recent years a number of CNMPs associated with CAFOs have been certified. In F2006, 8 CNMPs were certified, 34 were certified in FY2007, and another 7 certified in FY2008 (TCEQ, 2009). Communications with the TSSWCB indicate that two CNMPs were certified in FY2009 for CAFOs, and by the end of 2010, the TSSWCB had certified CNMPs for all 50 permitted CAFOs in the watershed (TCEQ, 2012).

While there is not a specific program that addresses phosphorus in the diet of dairy cattle, anecdotal evidence from dairy producers supported by local feed specialists and Texas AgriLife Extension Service (formerly Texas Cooperative Extension) indicates that lower phosphorus diets are being fed. In the mid to late 90s, a survey of dairy diet formulations including dairies in the North Bosque River watershed indicated that cow diets averaged 0.52 percent phosphorus (Sansinena et al., 1999). Revised recommendations by the National Research Council (NRC) indicate that about 0.38 percent phosphorus is optimal for high producing dairy cattle (NRC, 2001), which has been supported in various studies to reduce excess phosphorus in manure (Powel and Satter, 2005; Miller et al., 2010).

Two of the most visible projects associated with the I-Plan were the Dairy Manure Export Support (DMES) project and the Composted Manure Incentive Project (CMIP). The TSSWCB sponsored DMES project provided incentives to haulers to transport manure from dairies to composting facilities. Through CMIP, TCEQ provided oversight of composting facilities and rebates to Texas State agencies that use manure compost associated with the DMES project. The TCEQ and TSSWCB initiated these manure composting projects in September 2000 as a way to export dairy manure from the North Bosque River watershed. In turn, the dairy manure compost may be used in other watersheds as a beneficial soil amendment. The Texas Department of Transportation (TxDOT) has been the major user of dairy manure compost for roadside revegetation. Through August 2006, over 650,000 tons of dairy manure had been hauled to composting facilities and about 329,000 cubic yards of compost were exported from the watershed (TCEQ, 2009).

Funding for CMIP continued through August 2006, while the DMES project continued to pay incentives to haulers through February 2007. The idea behind these two projects was to establish a manure composting industry that would be self-sufficient after the ending of these incentive programs. Seven composting facilities were active during these projects, and as of March 2008, six were still active and receiving manure from dairy operations within the watershed. A follow up in May and June 2009 indicated that five of these six composting facilities were still active, but as of early 2012, TCEQ reported that only two composting facilities are still fully operational and one other is only sporadically receiving manure (TCEQ, 2012).

Another program that should have a notable impact on water quality, particularly under low flow conditions, is the implementation of phosphorus removal treatments by municipal WWTPs. There are seven municipal wastewater discharge facilities within the North Bosque River watershed (Stephenville, Hico, Meridian, Iredell, Cranfills Gap, Clifton, and Valley Mills). All municipal WWTPs are required as part of the I-Plan to monitor total phosphorus in their effluent, and the two larger facilities in Clifton and Stephenville, have had their permits amended in 2003 to require phosphorus limits that necessitate advanced treatment processes. In the fall of 2005, Stephenville began using biological treatment in conjunction with alum and polymers for phosphorus removal with the goal of meeting a daily average discharge limit of 1 mg/L. The Clifton WWTP started using alum as a chemical treatment to remove phosphorus in the spring of 2005.

A waste load allocation (WLA) has been set for all seven municipal WWTP as well as three other facilities not associated with municipalities (Northside Subdivision Water Corporation, Stephenville Mobile Home Park, and Western Dairy Transport). If the WLA cannot be met, each WWTP shall have its permit amended to 1 mg/L total phosphorus as a daily average effluent limit. As of August 31, 2010, TCEQ reported that all seven municipal WWTPs within the North Bosque River watershed have compliance schedules consistent with the WLAs in the TMDL and I-Plan (TCEQ, 2011).

Although I-Plan activities are occurring over varying timeframes, it is important to monitor and statistically evaluate water quality on a recurring basis to determine if improvements are occurring. It is anticipated that changes in water quality will be gradual and lag actual implementation on the land, particularly with regard to reducing nonpoint source pollutants, so it will require several years after implementation before instream improvements become apparent. To evaluate water quality along the North Bosque River, the Texas Institute for Applied Environmental Research (TIAER) has sampled stream stations since late 1995. Prior to 1995, TIAER's monitoring focused primarily on stream stations and tributaries within the upper third of the watershed providing a sampling history at some stations dating back to 1991.

While soluble phosphorus is the focus of the North Bosque River TMDLs, excessive nutrients based on a variety of nitrogen and phosphorus constituents, elevated chlorophyll-α (CHLA) concentrations, and elevated bacteria levels have been a concern in the North Bosque River watershed for over a decade. To more fully assess overall water quality improvements in the North Bosque River, trends are presented for nitrogen, phosphorus, CHLA, total suspended solids (TSS), specific conductance (conductivity), and bacteria concentrations. Field parameters, (e.g., dissolved oxygen and pH) while routinely monitored as instantaneous measurements, were not included in this trends analysis due to the difficulty in correcting for variations associated with diurnal fluctuations.

Background and Station Descriptions

North Bosque River Watershed

The North Bosque River is located in central Texas and extends about 180 river kilometers (110 river miles) from Stephenville, Texas to Lake Waco near Waco, Texas (Figure 1). The headwaters of the North Bosque River originate in Erath County just north of Stephenville. Lake Waco, a man-made reservoir, supplies drinking water to over 150,000 people. The North Bosque River watershed comprises about 74 percent of the land area draining into Lake Waco. Other major tributaries to Lake Waco include Hog Creek, the Middle Bosque River, and the South Bosque River. Stephenville is the watershed's largest city with an estimated population of about 17,000 (Table 1).

Table 1 Estimated city populations and wastewater discharge information for the North Bosque River watershed

Municipality	**Estimated 2010 Population[a]**	**Permitted Monthly Discharge (MGD)**	**Average of Monthly Reported Discharge for January - December 2011 (MGD) [b]**	**Average of Monthly Reported Total Phosphorus for January - December 2011 (mg/L) [b]**	**Discharge Location**
Stephenville	17,293	3.0	1.47 $\pm$ 0.08	0.70 $\pm$ 0.46	North Bosque River
Hico	1,404	0.25	0.091 $\pm$ 0.07	2.09 $\pm$ 1.33	Jacks Hollow Branch of the North Bosque River
Iredell	386	0.05	0.005 $\pm$ 0.002	2.90 $\pm$ 1.94	North Bosque River
Meridian	1,585	0.45	0.136 $\pm$ 0.025	2.15 $\pm$ 1.18	North Bosque River
Cranfills Gap	377	0.04	0.001 $\pm$ 0.001	2.65 $\pm$ 0.47	Austin Branch of Meridian Creek, which flows into the North Bosque River
Clifton	3,821	0.65	0.272 + 0.016	1.55 + 0.74	North Bosque River
Valley Mills	1,179	0.36	0.140 $\pm$ 0.011	2.05 $\pm$ 0.74	North Bosque River

[a] Population estimates based on values presented by the Texas State Data Center (2010) for January 1, 2010.
[b] Reported discharge in million gallons per day (MGD) and total phosphorus concentrations represent the average and standard deviation of monthly self-reported data for all seven municipalities (USEPA, 2012).

As mentioned previously, seven municipalities have WWTPs that discharge within the North Bosque River watershed. These are the cities of Stephenville, Hico, Iredell, Meridian, Cranfills Gap, Clifton, and Valley Mills (Table 1). Direct point source discharges occur to the North Bosque River from each community's WWTP, with the exception of Cranfills Gap and Hico. The Cranfills Gap WWTP discharges into the Austin Branch of Meridian Creek, a major tributary to the North Bosque River, and the Hico WWTP discharges into Jacks Hollow Branch a few hundred feet before its confluence with the North Bosque River. Three additional WWTPs are as follows:

- Northside Subdivision Water WWTP north of Stephenville with a permitted monthly discharge of 0.033 MGD into an unnamed tributary of the North Fork of the North Bosque River,
- Stephenville Mobile Home Park with a permitted discharge of 0.024 MGD into an unnamed tributary of Pole Hollow Branch, and
- Western Dairy Transport, which has a no discharge permit, with irrigated effluent applied to fields within the Indian Camp Creek drainage basin.

The North Bosque River watershed is typical of many watersheds in the region in that the dominant land covers are wood and range. Improved pasture and some row crop farming occur throughout the watershed. Row crop farming is most common in the southern portions of the watershed, particularly in the floodplain of the North Bosque River close to the city of Clifton. Improved pasture is predominately fields of Coastal bermudagrass (*Cynodon dactylon*), while row crops of sorghum (*Sorghum bicolor*) and winter wheat (*Triticum* spp.) are often grown as a double-crop system. A large number of dairies are located within the upper third of the watershed where producers have generally applied dairy waste to improved pasture and row crops as an organic fertilizer.

The headwaters of the North Bosque River are located in Erath County, which has been the number one milk-producing county in Texas for a number of years according to records maintained by the USDA Agricultural Marketing Service. While Erath County has been the top milk producing county in Texas for the past several years and for most of 2011, in August, October and November 2011, Castro County in the Pan Handle of Texas edged out Erath County in milk production (USDA-AMS, 2011). Within Erath County, the number of dairy producers has decreased substantially over the last several years (Figure 2), and while milk production has also decreased, it has not been proportional to the decline in producers. For reference, only about two-thirds of the dairy operations in Erath County are located within the North Bosque River watershed, and based on TCEQ inspection records for the North Bosque River watershed, the estimated number of dairy cows was about 45,000 in 2001 and only about 36,000 in 2009. In 2009, it was also estimated that another 8,000 animals were in the watershed in association with beef or calf raising CAFOs or AFOs bringing the total number of cattle in confinement to about 44,000.

Annual rainfall in the North Bosque River watershed averages a little over 76 cm (30 in) per year. Rainfall typically follows a slightly bimodal pattern with peaks in the spring and fall. On average the wettest month is May and the driest month is January. Most tributaries of the North Bosque River are highly intermittent and frequently become dry soon after each rainfall runoff event. In some years winter rains corresponding with low evapotranspiration rates can, however, establish a base flow that persists well into spring. Groundwater contributions in the upper portion of the watershed are fairly insignificant, though groundwater seepage has been noted in the lower portion of the watershed, particularly along Neils Creek. Neils Creek is a major tributary to the North Bosque River that joins the North Bosque River between Clifton and Valley Mills (Figure 1).

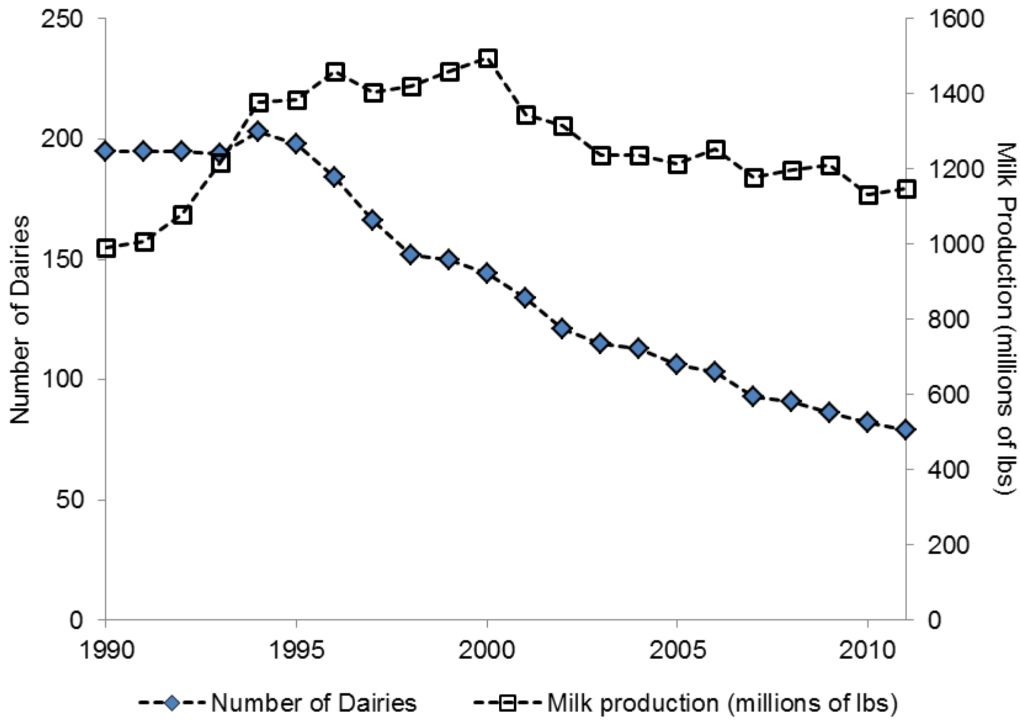

Figure 2 Annual variation in the number of dairy producers and milk production for Erath County Source: USDA-AMS milk marketing production records.

Sampling Stations

Because TIAER has sampled at many of these stations under separate projects, all stations are listed by their TCEQ and TIAER station identification for easy reference to information or data in other reports. The TCEQ station identification is generally listed first followed by the TIAER station identification in parentheses or brackets. Trend analysis activities focused on eight stream stations at which temporally intensive data collection has occurred for about 10 years or more. Of note, monitoring at most stations was initiated in the early to mid-1990s, while monitoring at station 18003 (BO083) was not initiated until 2003. These stations vary in drainage area, water quality, and hydrology (Table 2) and are grouped as follows:

- The five North Bosque River index stations (11954 [BO095], 11956 [BO090], 18003 [BO083], 11963 [BO040], and 17226 [BO020]) specified in the phosphorus TMDLs and I-Plan.
- North Bosque River at Hico, station 11961 (BO070), which is located in a long reach of the river where index stations are absent.
- Green Creek, station 13486 (GC100), which is collocated with one of TCEQ's Environmental Monitoring and Response System (EMRS) stations.
- Neils Creek, station 11826 (NC060), which is a reference or least disturbed stream for the Central Oklahoma-Texas Plains ecoregion.

Table 2 Sampling station characteristics. Land-use/land-cover information based on information from Narasimhan et al. (2005).

Station Identification TCEQ (TIAER)	Location within the North Bosque River Watershed	Drainage Area (ha)	Dominate Land Use or Land Cover[a]	General Water Quality and Hydrology
Stations along the Mainstem of the North Bosque River				
17226 (BO020)	North Bosque River above Stephenville, Texas	21,700	Wood-range (26%), pasture and cropland (53%), waste application fields (17%), urban (4%)	Water quality moderately impacted by nonpoint sources; intermittent flow with perennial pools
11963 (BO040)	North Bosque River below Stephenville, Texas about 0.6 km below the discharge from the Stephenville WWTP[b]	25,700	Wood-range (26%), pasture and cropland (51%), waste application fields (16%), urban (7%)	Water quality impacted by point and nonpoint sources; perennial flow
11961 (BO070)	North Bosque River at Hico, Texas above the discharge from the Hico WWTP	93,100	Wood-range (41%), pasture and cropland (46%), waste application fields (9%), urban (4%)	Water quality moderately impacted by point and nonpoint sources; nearly perennial flow
18003 (BO083)	North Bosque River between Iredell and Meridian, Texas	178,000	Wood-range (54%), pasture and cropland (36%), waste application fields (6%), urban (2%)	Water quality moderately impacted by point and nonpoint sources; nearly perennial flow
11956 (BO090)	North Bosque River at Clifton, Texas above the discharge from the Clifton WWTP	253,000	Wood-range (60%), pasture and cropland (33%), waste application fields (4%), urban (2%)	Low impacts from point and nonpoint sources; perennial flow
11954 (BO095)	North Bosque River at Valley Mills, Texas above the discharge from the Valley Mills WWTP	297,000	Wood-range (62%), pasture and cropland (31%), waste application fields (4%), urban (2%)	Low impacts from point and nonpoint sources; perennial flow
Stations on Major Tributaries to the North Bosque River				
13486 (GC100)	Green Creek near the confluence with the North Bosque River	25,200	Wood-range (39%), pasture and cropland (50%), waste application fields (8%), urban (2%)	Water quality moderately impacted by nonpoint sources; intermittent flow with perennial pools
11826 (NC060)	Neils Creek near the confluence with the North Bosque River	35,200	Wood-range (74%), pasture and cropland (24%), urban (1%)	Ecoregion reference site; intermittent flow with perennial pools

[a] Animal waste application fields are considered a distinct land use from pasture and cropland, although waste is generally applied to pasture and cropland.
[b] WWTP, wastewater treatment plant.

The land-use information in Table 2 is based on classification of satellite imagery from 2001 through 2003 conducted by the Spatial Sciences Laboratory of the Texas Agricultural Experiment Station, now Texas AgriLife Research (Narasimhan et al., 2005). Information on animal waste application fields was compiled in 2000 from TCEQ records and modified in the fall of 2007 by TIAER based on a review of TCEQ permit information to supplement the satellite imagery classification. The WAFs information includes milking and non-milking operations, although milking operations represent over 80 percent of the CAFOs and AFOs in the watershed. A goal of the current project is to update the WAF information for CAFOs and AFOs in the watershed, so it can be used to evaluate if changes have occurred in the amount and location of WAFs that might be related to changes in water quality. The task of updating the WAF information has been initiated and preliminary results are presented later in this report.

In addition to the stations listed Table 2, data from station 17605 (BO100) were used in conjunction with data from station 11954 (BO095). Station 17605 (BO100) was a TIAER sampling station located below Valley Mills that was discontinued in July 2001 due to bank stability problems. Station 11954 (BO095) was installed about three river kilometers upstream to replace station 17605 (B0100). Collectively data from these two stations will be referred to as station 11954 (BO095) throughout the rest of this report.

Sample Collection and Laboratory Analysis Methods

Quality Assurance Procedures

Beginning as early as 1992, TIAER has collected data from project stations under a variety of quality assurance project plans. Historical information used in this report includes water quality, rainfall, and streamflow. Historical project QAPPs include the following:

1. Quality Assurance Project Plan for the National Pilot Project (TIAER, 1993) funded by USEPA. This QAPP covers data collected between June 1, 1992 and August 31, 1995 for stations in the upper portion of the North Bosque River watershed.

2. Quality Assurance Project Plan for the Bosque River Watershed Pilot Project (BRA, 1995) funded by the TCEQ Clean Rivers Program via the Brazos River Authority with TIAER as a subcontractor. This QAPP covers data collected between October 1, 1995 and May 31, 1996.

3. Quality Assurance Project Plan for the Lake Waco-Bosque River Initiative (e.g., TIAER, 2005) funded by the United Stated Department of Agriculture. This QAPP covers data collected between September 1, 1996 and August 31, 2006.

4. Quality Assurance Project Plan for the North Bosque River Watershed Water Quality Assessment Clean Water Act 319(h) project funded by the TCEQ and

EPA Region 6 (e.g., TIAER, 2010a). This QAPP covers data collected between February 2006 and August 2010.

5. Quality Assurance Project Plan for the North Bosque River Watershed Water Quality Assessment project funded through the TCEQ Surface Water Quality Monitoring Program (TIAER, 2010b). This QAPP covers data collected between September 2010 and August 2011.

6. Quality Assurance Project Plan for Evaluating Effectiveness of I-Plan Activities within the North Bosque River Watershed, a Clean Water Act 319(h) project funded through the TCEQ Nonpoint Source Program (TIAER, 2011). This QAPP is for the current project and covers data presented in this report collected between September 2011 and December 2011.

Water quality data associated with projects above were collected and analyzed using similar assessment objectives, sampling techniques, laboratory protocols, and data validation procedures. One known area of deviation was in the measurement of bacteria. Prior to 2000 fecal coliform (FC) rather than *Escherichia coli* was monitored. McFarland and Millican (2010) evaluated paired *E. coli* and fecal coliform data from November 2000 through March 2004 to compare these two types of bacteria data. This period of overlap was used to determine if fecal coliform could be adjusted to comparable *E. coli* values using accepted statistical methods for comparing different analytical methods (Bland and Altman, 1986). This comparison included 1075-paired observations and produced the following regression relationship, which was used to adjust historical fecal coliform concentrations to *E. coli* concentrations prior to trend analysis:

$$\ln(E.\ coli) = 0.946*\ln(\mathrm{FC}) - 0.029 \qquad R^2 = 0.93$$

Of note, McFarland and Millican (2010) indicate that this regression relationship did not meet all the assumptions associated with use of regression analysis in that the distribution of residuals was peaked and, thus, not normally distributed even after data were log normally transformed. We assumed that the regression relationship between fecal coliform and *E. coli* was robust enough that the violation of this statistical assumption would have only a minor impact on the outcome of the trend analysis.

Another known deviation was in the use of reporting limits for left-censored data. Prior to September 2003, TIAER used laboratory method detection limits (MDLs) as reporting limits for constituents. After September 2003, TIAER used TCEQ ambient water reporting limits (AWRLs) or limits of quantitation (LOQs) as reporting limits. Data for each constituent were standardized prior to trend analysis to make sure that differences in the reporting limit did not cause an indication of false trends.

Data external to TIAER from the United States Geological Survey (USGS) were used to determine flow at some sampling stations. The USGS maintains stream stage gauging stations along the North Bosque River near Hico (USGS station 08094800), Clifton (USGS station 0809500), and Valley Mills (USGS station 08095200). Associated USGS stream discharge and/or rating curve data in conjunction with stage data measured by

TIAER were used to calculate discharge for stations 11961 (BO070), 11956 (BO090), and 11954 (BO095).

The overall project objective was to use direct data in conjunction with non-direct data from previous projects to evaluate changes in water quality over time. Because most historical data were collected and analyzed in a comparable manner, no limitations were placed on their use, except where known deviations occurred, such as changes in bacteria parameters and differences in reporting limits.

Collection Methods for Routine Grab Samples

Routine grab sampling at stream stations occurred at least monthly and generally on a biweekly schedule throughout the period of available data. Grab samples were collected only when water was flowing at a station and not when the stream was dry or pooled. Grab samples were generally taken at a depth below the surface of about 0.08 to 0.15 meters (0.25 to 0.5 ft), as recommended in TCEQ surface water monitoring procedures (TCEQ, 2003; 2008).

When grab samples were collected, water temperature, dissolved oxygen (DO), pH, and conductivity were measured in situ with a Hydrolab or YSI (multiprobe) field sampling instrument. Because stream stations within the North Bosque River watershed are generally shallow and unlikely to stratify, multiprobe readings were taken only at a surface depth of about 0.3 meters (1.0 ft).

In this report, surface samples are presented and evaluated for trends in nutrients, TSS, CHLA, bacteria (as *E. coli*) and conductivity. Trends in water temperature, DO, and pH were not evaluated, because many physical parameters, particularly water temperature and DO, follow a diurnal pattern that causes values to vary depending on the time of day when measurements were taken.

Collection Methods for Storm Samples

Storm samples were collected at seven of the eight North Bosque River stream stations. Only routine grab samples were collected at station 18003 (BO083) due to issues with accessibility for installation of a storm sampling station. Storm samples were collected at automated sampling stations using an ISCO 3700 sampler in combination with an ISCO 4230 or 3230 bubbler-type flow meter. The ISCO flow meter operates by measuring the pressure required to force an air bubble through a 3 mm (0.125 in) polypropylene tube, or bubbler line, and represents the water level. The ISCO flow meters were programmed to record water level or stage continuously at five-minute intervals and to initiate sample retrieval by the ISCO 3700 samplers. Samplers typically were actuated based on a stream rise of about 4 cm (1.5 in) above the bubbler datum. Once activated, samplers were programmed to retrieve one-liter sequential samples. Historically, the typical sampling sequence at major tributary and mainstem stream stations was:

- An initial sample
- One sample taken at a one-hour interval
- One sample taken at a two-hour interval
- One sample taken at a three-hour interval
- One sample taken at a four-hour interval
- One sample taken at a six-hour interval
- All remaining samples taken at eight-hour intervals

Since the fall of 2006, the sampling sequence has been modified so that once the four-hour interval was encountered; all remaining bottles for an event were then taken at the four-hour interval.

Until June 1997, most storm samples were analyzed individually by TIAER's laboratory. To decrease sample load to the laboratory, a flow-weighting strategy was initiated that composited samples on about a daily basis. This flow-weighting strategy was initiated in May or June 1997 at stations 17226 (BO020), 11963 (BO040), 13486 (GC100), and 11826 (NC060). In May 2000, the flow-weighting strategy for storm samples was initiated at stations 11956 (BO090) and 11954 (BO095).

At each storm sampling station, stream stage was continuously monitored at five-minute intervals. To convert stage readings to flow, stage-discharge relationships were developed. For stations 17226 (BO020), 11963 (BO040), 13486 (GC100), and 11826 (NC060), stage-discharge relationships were based on manual flow measurements by TIAER staff taken at various stage conditions that were then related to the cross-sectional area of the stream following USGS methods as outlined in Buchanan and Somers (1969). Stage-discharge relationships for stages above available measurements were extrapolated using the cross-sectional area and a least-squares relationship of the average stream velocity to the log of water level.

Stations 11961 (BO070), 11956 (BO090), and 11954 (BO095) are located near USGS stream gauging stations. Station 11961 (BO070) is located near USGS station 08094800, 11956 (BO090) is located near USGS station 0809500, and 11954 (BO095) is located near USGS station 08095200. Very early in TIAER's monitoring program, stage recordings at station 11961 (BO070) were tied into the USGS rating curve for station 08094800. The daily average discharge values at station 08094800 were used as a check on the TIAER estimates of discharge at station 11961 (BO070) until October 1999, when the USGS station 08094800 near Hico was converted to flood-hydrograph partial record station. For stations 11956 (BO090) and 11954 (BO095), continuous 15-minute discharge data were obtained for USGS stations 0809500 and 08095200. Of note in October 2005 the USGS station 08095200 near Valley Mills was also converted to a flood-hydrograph partial record station. To obtain continuous discharge measurements after October 1, 2005, a period with USGS discharge measurements and TIAER stage recordings was used to develop a stage-discharge relationship for station 11954 (BO095) in conjunction with manual flow measurements collected by TIAER. This new rating curve for station 11964 (BO095) was used for discharge estimates after October 1, 2005 and USGS 15-minute discharge data were used prior to October 1, 2005. Starting in

September 2007, the USGS station near Valley Mills (08095200) was converted back to recording all flows, but TIAER has continued to use stage and flow data from 11964 (BO095) with adjustments based on USGS data when data gaps occur.

Of note, heavy rains in late June 2007 led to flooding necessitating the temporary removal of automated sampling equipment from stations 11954 (BO095) at Valley Mills and 11956 (BO090) at Clifton. The automated sampler at station 11956 (BO090) was inoperable from June 27, 2007 through July 20, 2007. The automated sampler at station 11954 (BO095) was inoperable from June 27, 2007 through August 16, 2007. While automated samplers at 11956 (BO090) and 11954 (BO095) were inoperable, daily storm grabs were taken for laboratory analyses when water levels were elevated. The temporary removal of these two sampling stations corresponded with a period when the USGS was providing flow and stage data at nearby stations, so flow and stage from the corresponding USGS stations were used to estimate missing stream flow and stage data for 11956 (BO090) and 11954 (BO095).

Also of note in the spring of 2008, the monitoring design was changed due to changes in project funding so that only selected storm events rather than all events were to be monitored. Because of judicious efforts on the part of the field crew and favorable weather conditions, the project was able to monitor all storm events in 2008 while missing only a few relatively small events in 2009. In late November 2009, there was one event, which caused a small rise in water level at most stations, but led to a moderately sized runoff event at stations 11961 (BO070) and 13486 (GC100) during which storm samples were not collected. A routine grab sample was collected during this November 2009 event, which was used to represent the storm water quality for this event.

During most of 2010, storm sampling was restricted due to limited funding. From January through May 2010, storm samples were collected only at stations 11961 (BO070) and 11954 (BO095). From May through September 2010, storm samples were not collected at any of the seven stations. Starting in September 2010, renewed funding was obtained at which time storm sampling was reinitiated at all seven storm stations, so all events with a rise in water level of over 0.5 ft between September and December 2010 would be monitored.

Although several storms during 2010 were not directly monitored, the contribution of these storms to nonpoint storms loadings was still important to consider in evaluating trends through 2010. Because it is anticipated that changes in water quality will occur gradually, data from storms evaluated in 2009 and 2010 for most stations were used to estimate storm loadings. Of note for station 13486 (GC100), storm data from 2008 were included due to the paucity of storms that occurred at this station in 2009. Details on how previous storm concentrations were associated with 2010 storm events are presented in McFarland and Millican (2011).

In 2011, most months had relatively little rainfall and extreme drought conditions occurred across the watershed by late summer, enabling all events that occurred to be monitored. Routine grab sampling was limited during the summer months as sites 17226

(BO020), 11961 (BO070), 18003 (BO083), 11826 (NC060), and 12486 (GC100) (see McFarland and Adams, 2012).

Laboratory Analysis Methods

Ammonia-nitrogen (NH_3-N), nitrite-nitrogen plus nitrate-nitrogen (NO_2-N+NO_3-N), total Kjeldahl nitrogen (TKN), orthophosphate-phosphorus (PO_4-P) or SRP, total-P, and TSS were evaluated for both routine grab and storm samples (Table 3). In addition, CHLA and *E. coli* were evaluated for routine grab samples. Total nitrogen (TN) was calculated as the sum of NO_2-N+NO_3-N plus TKN for inclusion in the trend analysis.

Prior to 2000 fecal coliform rather than *E. coli* was monitored as an indicator of bacteria concentrations. From November 2000 through March 2004 both fecal coliform and *E. coli* were analyzed to determine a relationship between these two measures of bacteria.

Table 3 Parameter and methods of analysis for water quality samples used in trend analysis

Parameter	Abbreviation	Units	Method[a]	Parameter Code
Ammonia-nitrogen	NH_3-N	mg/L	EPA 350.1 or SM 4500-NH3 G	00608
Nitrite-nitrogen + nitrate-nitrogen	NO_2-N+NO_3-N	mg/L	EPA 353.2 or SM 4500-NO3-F	00631
Total Kjeldahl nitrogen	TKN	mg/L	EPA 351.2 or SM 4500-NH3G[b]	00625
Orthophosphate-phosphorus	PO_4-P	mg/L	EPA 365.2 or SM 4500P-E	70507 or 00671[c]
Total phosphorus	Total-P	mg/L	EPA 365.4[b]	00665
Total suspended solids	TSS	mg/L	EPA 160.2 or SM 2540 D	00530
Chlorophyll-α	CHLA	µg/L	SM[d] 10200-H	32211
Escherichia coli	*E. coli*	cfu/100 mL or MPN/100mL	SM9222G or SM9223-B (IDEXX Coliert®)[d]	31699

[a] EPA refers to *Methods for Chemical Analysis of Water and Wastes* (USEPA, 1983) and SM refers to *Standard Methods for the Examination of Water And Wastewater*, 18th Edition (APHA, 1992) for PO_4-P and latest online edition for all other parameters.
[b] Modification of TKN and total-P methods involved using copper sulfate as the catalyst instead of mercuric oxide.
[c] Field-filtering for PO_4-P began in October 2003 for routine grab samples as indicated by parameter code 00671. All routine samples prior to October 2003 and all storm samples were lab filtered as indicated by parameter code 70507.
[d] Most probably number (MPN) or IDEXX method for *E. coli* (SM9223-B) was implemented in April 2004.

Data Set Construction and Statistical Methods for Trend Analysis

Two data sets representing monthly estimates of average constituent concentrations for each station were developed for trend analysis. The first data set was developed from routine grab data, while the second data set was developed from a combination of routine grab and storm data. Evaluation of these two data sets allows trends with regard to the TMDL objectives to address reductions in concentrations and loadings. Routine grab samples should reflect any decrease in concentrations associated with routine monitoring, while the volume-weighted data set including storm samples should reflect any decrease in loadings at stream stations. Stream concentrations are often related to flow, so for all stream stations except 18003 (BO083) where flow was not available, data sets were limited to timeframes with flow data for evaluation of trends.

Most routine grab samples for nutrients and TSS were collected biweekly or monthly, while samples for analysis of CHLA and bacteria were collected only monthly. Estimates of instantaneous discharge at the time of routine grab sample collection were determined from stage recordings and paired with each biweekly or monthly grab sample as an indicator of flow. Because variation in sampling frequency over time can cause unintended impacts on the analysis of trends (Gilbert, 1987), concentrations and flows associated with biweekly samples were averaged to represent values on a monthly basis. Except at station 18003 (BO083), concentrations represented monthly flow-weighted averages to account for differences in instantaneous flow between individual grab samples within a month.

The second data set represented volume-weighted, average-monthly constituent concentrations based on calculations of total flow and loadings using routine grab and storm samples. Monthly masses and flows were calculated using a rectangular integration method applying a midpoint rule to associate water quality concentrations with streamflow (Stein, 1977). The interval for stage readings (5 minutes for TIAER stations and generally 15 minutes for USGS gauging stations) was the minimum measurement interval. The flow associated with each interval was multiplied by the associated water quality concentration and summed across the entire month to calculate total monthly constituent loadings. Monthly volume-weighted concentrations were calculated by dividing total monthly mass for a constituent by total monthly flow.

Of note for 2010, the volume-weighted data set includes estimated event mean concentrations (EMCs) for events that were not monitored; because very few storm events were directly monitored between January and August 2010 (see McFarland and Millican, 2011). Some storm sampling occurred between January and May 2010 at stations 11961 (BO070) and 11954 (BO095), but at all other stations, only routine grab sample data were directly collected until September 2010, when storm sampling was reinitiated at all seven stations.

In the calculation of loadings for 2010, EMCs calculated for storms monitored in 2009 and 2010 (and 2008 for station 13486) were used to estimate storm loadings when direct measurements were missing. Because EMCs are expected to vary with the size of the event, EMCs were compared to the average flow for each event generally using a log-linear relationship. Several studies have shown strong relationships between constituent concentrations and discharge (e.g., Agouridis and Edwards, 2003; Sharpley et al., 2008) and calculation of loadings is often based on non-direct measurements (e.g., Cohn et al., 1992; Robertson and Roerish, 1999). Stream level data for 2010 was then evaluated at each station to determine when storm events occurred that were not directly monitored and the average flow during each of these events was calculated. Based on the average flow of each event, EMCs were calculated using the parameter specific relationship developed for each station between flow and EMC (see Appendix A in McFarland and Millican, 2011). If there was not a clear relationship for a given parameter with average storm flow, the average EMC was used to estimate loadings for non-monitored events.

Censored Data

Analytical laboratories generally present data based on a reporting limit, where the reporting limit is the lowest concentration at which the laboratory will quantitatively report data as different from zero. Values below the reporting limit are generally indicated as less than the reporting limit or left censored. Left censored data can cause problems with trend analysis, especially when changes in the reporting limit occur over time. If differences due to variation in reporting limits are not accounted for prior to trend analysis, false trends may be observed. For example, if a relatively high reporting limit is used early and a lower reporting limit later in a project, a decreasing trend may be statistically shown that is not real if concentrations from the earlier data were actually lower than the later reporting limit. As part of the quality assurance of a project, reporting limits should be low enough that relevant changes in values can be observed.

For most projects prior to September 2003, TIAER used laboratory method detection limits (MDLs) as the reporting limit. These MDLs were updated about once every six months. After September 2003, most TIAER projects used TCEQ defined ambient water reporting limits (AWRLs) or limits of quantification (LOQs) as the reporting limit, although if not specified for a project, MDLs were still implemented. Following recommendations by Gilliom and Helsel (1986) and Ward et al. (1988), values measured below the laboratory reporting limit or left censored data were entered as one-half the reporting limit. In preparing data sets for trend analysis, the maximum reporting limit for each station by constituent was determined and all values below the maximum reporting limit were set equal to one-half the maximum reporting limit.

Monitoring History

Because monitoring was conducted under a number of different projects, different lengths of record were available for each station (Table 4). The timeframe of available monitoring data also often differed by parameter. Stations 11961 (BO070) and 13486 (GC100) had the longest periods of record with data starting in 1993 for most routine grab and storm samples. With routine grab samples, TKN, total P, and TSS were not analyzed until 1994 at 11961 (BO070) and 1995 at 13486 (GC100), but these three constituents were analyzed with storm samples starting in 1993 at both stations. Loading estimates at 11961 (BO070) in 1993 and 13486 (GC100) in 1993 and 1994 for TKN, total P, and TSS were, thus, based only on storm data. Also, at 13486 (GC100), CHLA was not added to the analysis of routine grab samples until 1996. Consistent data sets for all constituents, whether routine or storm data, were indicated at station 17226 (BO020) starting in 1997; at station 11963 (BO040) starting in 1994; and at stations 11956 (BO090), 11954 (BO095), and 11826 (NC060) starting in 1996.

Exploratory Data Analysis (EDA)

Exploratory data analysis (EDA) was used initially to evaluate each data set. The EDA graphical technique is used to characterize distributional properties, identify outliers and patterns, and select appropriate statistical tests (Tukey, 1977). Histograms, time series, and box and whisker plots, blocked by month and by year, were used. Histograms and the Shapiro-Wilk statistic were used to test for normality. The Shapiro-Wilk statistic showed that most water quality variables were not normally distributed. Natural log ($\log_e$ abbreviated as ln) transformation improved the distribution and homogeneity of variance for routine grab and volume-weighted data sets.

Table 4 Years of available sampling data for trend analysis by station and parameter type

	Routine Grab Samples					Storm Samples	
Station	**Conduct-ivity**	**Soluble Nutrients**	**TKN, Total-P, and TSS**	**CHLA**	**Bacteria**	**Soluble Nutrients**	**TKN, Total-P, and TSS**
17226 (BO020)	1997 – 2011	1997 – 2011	1997 – 2011	1997 – 2011	1997 – 2011	1997 – 2011	1997 – 2011
11963 (BO040)	1994 – 2011	1994 – 2011	1994 – 2011	1994 – 2011	1994 – 2011	1994 – 2011	1994 – 2011
11961 (BO070)	1993 – 2011	1993 – 2011	1994 – 2011	1993 – 2011	1994 – 2011	1993 – 2011	1993 – 2011
18003 (BO083)	2003 – 2011	2003 – 2011	2003 – 2011	2003 – 2011	2003 – 2011	not applicable	not applicable
11956 (BO090)	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011
11954 (BO095)	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011
13486 (GC100)	1993 – 2011	1993 – 2011	1995 – 2011	1996 – 2011	1995 – 2011	1993 – 2011	1993 – 2011
11826 (NC060)	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011	1996 – 2011

Time series and box and whisker plots identified patterns and described variability in the data. In addition, time series and box plots provided insight regarding the presence of trend and seasonality. Seasonality is a systematic variation that, if present, confounds the true trend. Removing seasonality prior to trend analysis is important, because a significant positive trend in one season and a significant negative trend in another season can result in a finding of no trend when evaluated together. The presence of seasonality in the data was statistically evaluated using a correlogram of monthly data as described by Reckhow et al. (1993). A correlogram expresses how the correlation of pairs of water quality data changes with time. A significant correlation at lags representing 6 and 12 months generally indicates seasonality (Reckhow et al., 1993). A significant correlation at shorter lags (lags representing 1 or 2 months) indicates autocorrelation. For the parameters and sites evaluated seasonality was not significant, so seasonality did not need to be separately accounted for in the trend analysis.

Adjustment for Stream Flow

Another confounding factor in trend analysis of stream water quality data is variation in flow or volume and its influence on concentration. For example at stream stations where point source contributions dominate, increased flows associated with storm runoff may act to dilute concentrations, so concentrations decrease with increasing flows. In contrast at stream stations where nonpoint source contributions dominate, increasing concentrations may occur with increasing flow. Details on methods for removing ancillary effects associated with flow are discussed in Helsel and Hirsch (1992). The two most commonly used methods are simple linear regression and locally weighted scatter-plot smoothing (LOWESS) (Helsel and Hirsch, 1992; Cleveland, 1979). The LOWESS method is preferred over simple linear regression as an adjustment method, because the relationship between most ancillary variables, such as flow or volume, and concentration is usually nonlinear (Helsel and Hirsch, 1992; Bekele and McFarland, 2004).

The LOWESS method is an extension of simple linear regression in that it fits simple regression models to localized subsets of the data to build up a function that describes the deterministic variation in the data. The local regression is fit using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away. A user-specified input called the "smoothing parameter" (*f*) determines how much data are used to fit each localized regression. Values of *f* range from 0 to 1 with 1 using each individual data point as in simple linear regression. Large *f* values produce the smoothest functions that "wiggle" the least in response to fluctuations in the data, while smaller *f* values fit functions that more closely conform to the data. Using too small an *f* value is not desirable, because the regression function will start to capture the random error in the data (SAS Institute, 1999).

An *f* value of 0.5 was used as recommended by USGS (Langland et al., 1998) and later confirmed to be optimum for data from the North Bosque River watershed (Bekele and McFarland, 2004). The PROC LOESS procedure of SAS (SAS Institute, 1999) was used to develop the LOWESS regression relationships. Residuals associated with the LOWESS regression of flow with concentration were then used in trend testing as flow-adjusted concentrations. At stream stations, monthly average stream flow was calculated as the average of instantaneous measures with grab samples or as the total volume of flow divided by the number of seconds in a month with volume-weighted data. Flows and concentrations were transformed using a natural-log transformation prior to applying the LOWESS regression to decrease the variance in the regression residuals.

Trend Testing

The presence of trend was tested using the nonparametric Kendall's tau as described in Reckhow et al. (1993). The Kendall's tau test is suitable for water quality data that show a non-normal distribution, contain missing data, and are censored with values below method detection or reporting limits (Gilbert, 1987; Hirsch and Slack, 1984). The Kendall's tau statistic can also be modified to address seasonality, if present.

The Kendall's tau test is based on a rank order statistic. That is, it compares ranks rather than actual data values. Observations are ordered by date (assuming seasonality is not present) and the difference between successive pairs of observations is calculated. The Kendall's tau statistic is based on the number of positive versus negative differences from successive pairs to determine if the dataset is increasing or decreasing over time. When seasonality exists, data are grouped by season for comparisons often with each month representing a separate season. An increasing trend exists when significantly more data pairs increase than decrease; a decreasing trend exists when significantly more data pairs decrease than increase; and if pairs decrease and increase at the same frequency, no trend exists (Newell et al., 1993).

Trend testing was done on flow-adjusted monthly data sets for all stream stations, except station 18003 (BO083) where flow data were not available. The null hypothesis tested was that there was no temporal trend in concentration of water quality constituents. The level of significance used to test the null hypothesis was 0.05. The slope calculated gives the magnitude of the trend and is interpreted as the change in concentration per month on a natural log scale. The slope in original units was computed on the natural log scale and calculated on an annual basis as follows (Helsel and Hirsch, 1992):

$$\% \text{ change/year} = (e^{b1} - 1)*100*12$$

Where "e" is the base of the natural logarithm and approximately equals 2.7183; and "b1" is the slope for the natural log transformed data[3].

[3] In previous trend reports (e.g., McFarland and Millican, 206, 2007, 2008, 2009, and 2010), the equation for annual percent change was incorrectly calculated as the percent change per month in that the 12 was inadvertently left out of the equation. In Tables 5-9 of this report all slopes are provided as annual rates of change including those taken from previous reports.

Trend Analysis Results

Routine Grab Data

In comparing from year to year, grab samples generally indicated similar positive or negative trends, if significant, regardless of end year, although the percent change per year often varied (Table 5). Slopes representing the percent change per year frequently decreased with increasing end year, most notably for parameters at stations 11956 (BO090) and 11954 (BO095). These decreasing slopes over time may indicate a step trend, in which decreases occurred at a given point in time and then stayed at a lower value, or possibly decreases that have occurred in the past that are now starting to increase. In contrast at station 11963 (BO040), slopes associated with both phosphorus parameters became more negative with increasing end year.

At station 17226 (BO020), no significant trends were indicated for any parameters for data through 2011. In earlier reports, a decreasing trend in conductivity and NO_2-N+NO_3-N had been noted and an increasing trend in TSS, but the most recent years of analysis (2009 through 2011) indicated no significant trend for either of these parameters.

At station 11963 (BO040), significant downward trends were indicated for NH_3-N, PO_4-P, TKN, and total-P. Previous reports have also indicated a negative trend for NO_2-N+NO_3-N at 11963 (BO040) for data evaluated through 2007, but data through 2011 indicated a slight increasing trend for NO_2-N+NO_3-N. Of note, significant decreasing trends for PO_4-P and total-P at station 11963 (BO040) have only been noted since 2007.

Downward trends in PO_4-P also occurred at station 11961 (BO070). These downward trends in PO_4-P were first noted with analysis of data through 2008. At station 11961 (BO070), downward trends were also noted for conductivity, CHLA, NH_3-N, NO_2-N+NO_3-N and total-P for data through 2011. Similar downward trends in nutrients have been indicated since 2008 at 11961 (BO070), but only NH_3-N consistently indicated a significant downward trend for all seven years of analysis.

At stations 11956 (BO090) and 11954 (BO095), significant downward trends were indicated for most parameters in evaluating data through 2011 (Table 5). At 11956 (BO090), no trends were noted for conductivity, CHLA, NO_2-N+NO_3-N or total-P. At 11954 (BO095), no trends for data through 2011 were noted for conductivity, CHLA, *E. coli*, NO_2-N+NO_3-N or total-N. Of note in earlier trend analyses (data evaluated through 2005 and 2006), decreasing trends for total-P and CHLA were noted at both 11956 (BO090) and 11954 (BO095). No significant trends for total-P at 11954 (BO095) occurred for data representing end years 2007-2010, but a significant downward trend again emerged for total P with data through 2010 and 2011.

Table 5 Trend results for routine grab data for stations with flow data along the mainstem of the North Bosque River. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. Significant slopes indicated at a p-value of 0.05.

		2011 Results			Slope (% change/yr)						
TCEQ (TIAER) Station	**Parameter**	**Period Evaluated**	**Kendall Test Statistic**	**p-value**	**End Year 2011**	**End Year 2010[a]**	**End Year 2009[a]**	**End Year 2008[a]**	**End Year 2007[a]**	**End Year 2006[a]**	**End Year 2005[a]**
17226 (BO020)	Conductivity	1997-2011	-0.091	0.1137		-2.9	-5.0	ne[b]	ne	ne	ne
	CHLA	1997-2011	-0.008	0.8924							
	E. coli	1997-2011	-0.083	0.1979							
	NH_3-N	1997-2011	-0.081	0.1606							
	NO_2-N+NO_3-N	1997-2011	-0.076	0.1858					-7.8		-13.3
	PO_4-P	1997-2011	0.036	0.5282							
	TKN	1997-2011	0.035	0.5404							
	Total-P	1997-2011	0.017	0.7735							
	TSS	1997-2011	0.091	0.1137				5.3	6.8	9.6	10.2
	Total-N	1997-2011	-0.010	0.8626					ne	ne	ne
11963 (BO040)	Conductivity	1994-2011	-0.069	0.1316			-2.9	ne	ne	ne	ne
	CHLA	1994-2011	-0.044	0.3504							
	E. coli	1994-2011	-0.048	0.3014							
	NH_3-N	1994-2011	-0.212	0.0000	-6.2	-7.6	-8.4	-8.9	-6.1	-5.2	
	NO_2-N+NO_3-N	1994-2011	0.092	0.0457	2.0				-3.1	-3.8	-5.6
	PO_4-P	1994-2011	-0.340	0.0000	-7.9	-7.4	-5.8	-4.7	-3.6		
	TKN	1994-2011	-0.218	0.0000	-3.0	-4.0	-4.6	-4.9	-3.4	-2.8	-2.2
	Total-P	1994-2011	-0.343	0.0000	-7.1	-6.7	-5.0	-4.2	-3.1		
	TSS	1994-2011	-0.041	0.3742							
	Total-N	1994-2011	0.031	0.4959					ne	ne	ne
11961 (BO070)	Conductivity	1993-2011	-0.168	0.0003	-1.2	-1.2	-1.4	ne	ne	ne	ne
	CHLA	1993-2011	-0.095	0.0464	-2.4				-3.8		
	E. coli	1994-2011	-0.066	0.1766					-7.0		
	NH_3-N	1993-2011	-0.290	0.0000	-3.6	-4.0	-4.3	-4.4	-6.1	-5.3	-8.9
	NO_2-N+NO_3-N	1993-2011	-0.144	0.0018	-4.4	-4.3	-4.0	-4.4			-6.2
	PO_4-P	1993-2011	-0.207	0.0000	-5.5	-5.0	-4.3	-4.0			
	TKN	1994-2011	-0.046	0.3282		-1.4	-2.2	-2.3	-2.5		
	Total-P	1994-2011	-0.251	0.0000	-4.5	-4.4	-4.2	-4.3	-3.4		-4.2
	TSS	1994-2011	0.016	0.7304							
	Total-N	1994-2011	-0.125	0.0081	-1.6	-2.3	-2.8	-3.0	ne	ne	ne

TCEQ (TIAER) Station	Parameter	2011 Results			Slope (% change/yr)						
		Period Evaluated	**Kendall Test Statistic**	**p-value**	**End Year 2011**	**End Year 2010[a]**	**End Year 2009[a]**	**End Year 2008[a]**	**End Year 2007[a]**	**End Year 2006[a]**	**End Year 2005[a]**
11956 (BO090)	Conductivity	1996-2011	-0.030	0.5410		-0.7		ne	ne	ne	ne
	CHLA	1996-2011	-0.009	0.8639						-5.5	-9.7
	E. coli	1996-2011	-0.115	0.0216	-4.1	-5.0	-4.7	-5.0	-6.7	-7.9	-10.8
	NH_3-N	1996-2011	-0.341	0.0000	-3.6	-4.1	-4.1	-4.8	-8.5	-5.3	-5.0
	NO_2-N+NO_3-N	1996-2011	-0.084	0.0861		-5.8	-5.0	-4.4		-5.9	-8.8
	PO_4-P	1996-2011	-0.162	0.0009	-3.6	-4.0	-4.7	-5.6	-12.2	-8.8	-20.4
	TKN	1996-2011	-0.142	0.0035	-2.5	-4.1	-5.9	-5.5	-4.8	-3.8	-5.9
	Total-P	1996-2011	-0.026	0.5954						-2.0	-4.6
	TSS	1996-2011	-0.135	0.0057	-2.7	-3.7	-3.1	-3.0	-4.9	-5.6	-10.4
	Total-N	1996-2011	-0.210	0.0000	-3.0	-4.9	-5.5	-5.3	ne	ne	ne
11954 (BO095)	Conductivity	1996-2011	0.022	0.6515			-4.7	ne	ne	ne	ne
	CHLA	1996-2011	-0.011	0.8285						-6.2	-10.8
	E. coli	1996-2011	-0.093	0.0587		-3.7		-4.9	-8.8	-7.2	-7.8
	NH_3-N	1996-2011	-0.222	0.0000	-2.3	-3.4	-4.0	-4.2	-6.2	-4.8	-6.1
	NO_2-N+NO_3-N	1996-2011	-0.066	0.1729		-1.2					
	PO_4-P	1996-2011	-0.272	0.0000	-4.4	-5.2	-5.3	-5.9	-7.1	-8.8	-17.3
	TKN	1996-2011	-0.105	0.0313	-1.8	-3.4	-4.4	-5.5	-5.3	-4.4	-5.3
	Total-P	1996-2011	-0.102	0.0355	-1.0	-1.7				-2.0	-5.6
	TSS	1996-2011	-0.136	0.0053	-2.9	-4.1	-3.7	-5.3	-6.4	-7.1	-11.6
	Total-N	1996-2011	-0.078	0.1084		-1.7	-2.4	-2.8	ne	ne	ne

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, and 2011).
[b] ne indicates parameter was not evaluated for noted end year.

Results for 18003 (BO083) are presented separately from the other mainstem stations, because data for 18003 (BO083) were not flow adjusted and represent a much shorter period of record (Table 6). Monitoring at station 18003 (BO083) also did not begin until 2003, which is several years later than at any of the other stations.

Similar to previous trend reports, a downward trend was indicated at station 18003 (BO083) for NH_3-N. Of note, the downward trend for NH_3-N for data through 2010 and 2011 was significant but indicated a zero slope value (Table 6). A zero slope estimate that is significant can occur when values have multiple ties, particularly if many values are at the reporting limit (McBride, 2000). An increasing trend in CHLA was indicated for data through 2011, but with a decreasing magnitude in the slope compared annual results since 2007. TKN, total-P, TSS, and total-N also showed upward trends for data through 2011 at station 18003 (BO083).

At station 13486 (GC100) located on Green Creek, downward trends were noted for conductivity, CHLA, NH_3-N, and PO_4-P (Table 7). Downward trends in PO_4-P and NH_3-N have been consistent for all years of analysis at 13486 (GC100). Only in the most recent year (2010) have decreasing trends in conductivity and CHLA been noted. At station 11826 (NC060) on Neils Creek downward trends were indicated for NH_3-N and PO_4-P for data through 2011. At 11826 (NC060), PO_4-P was the only parameter that consistently showed a downward trend, regardless of end year evaluated. Of note, 11826 (NC060) showed a significant increasing trend in *E. coli*, but this is the only end year to indicate such a trend.

Volume-Weighted Data

Generally, trends observed in previous years at mainstem stations continued to be observed with the analysis of volume-weighted data through 2011 (Table 8). Except for TSS at station 11963 (BO040), no increasing trends were indicated at any of mainstem stations for the volume-weighted data analyzed through 2011, but several decreasing trends occurred. At station 17226 (BO020), decreasing trends were indicated NH_3-N, NO_2-N+NO_3-N, and total-N. Decreasing trends were indicated at 11963 (BO040) for NH_3-N, PO_4-P, and total-P. For data through 2011, station 11961 (BO070) indicated decreasing trends for all constituents but TSS. At station 11956 (BO090), decreasing trends were found for all constituents but total-P and TSS through 2011, while at station 11954 (BO095), decreasing trends were indicated for all constituents but NO_2-N+NO_3-N.

For data through 2011, station 13486 (GC100) on Greens Creek showed a decreasing trend in NH_3N, but increasing trend in NO_2-N+NO_3-N and, thus, total-N (Table 9). Of note, decreasing trends had previously been indicated for PO_4-P at station 13486 (GC100) through end year 2008. Station 11826 (NC060) on Neils Creek showed decreasing trends in NH_3-N and PO_4-P for data through 2011 with similar trends also indicated for NH_3-N and PO_4-P in all previous years evaluated (Table 9). Several previous years had also indicated a decreasing trend in TKN that was not apparent in the most recent years of analysis.

Table 6 Trend results for routine grab data for station 18003 (BO083) along the mainstem of the North Bosque River. Data were transformed using a natural log transformation prior to trend analysis. Flow data were not available for this station, so water quality data were not flow-adjusted prior to trend evaluation. Significant slopes indicated at a p-value of 0.05.

TCEQ (TIAER) Station	Parameter	2011 Results			Slope (% change/yr)						
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2011	End Year 2010[a]	End Year 2009[a]	End Year 2008[a]	End Year 2007[a]	End Year 2006[a]	End Year 2005[a]
18003 (BO083)	Conductivity	2003-2011	0.084	0.2344				ne[b]	ne	ne	ne
	CHLA	2003-2011	0.262	0.0002	14.4	17.4	19.6	21.5	23.4		
	E. coli	2003-2011	-0.007	0.9304							
	NH_3-N	2003-2011	-0.267	0.0000	0.0	-0.0	-1.8	-7.7	-22.7	-44.8	-45.5
	NO_2-N+NO_3-N	2003-2011	-0.031	0.6164							
	PO_4-P	2003-2011	-0.096	0.1656							
	TKN	2003-2011	0.144	0.0402	5.5						
	Total-P	2003-2011	0.128	0.0663	4.4	6.1	8.9				-22.1
	TSS	2003-2011	0.169	0.0157	8.1	7.4	12.0				
	Total-N	2003-2011	0.120	0.0869	5.1				ne	ne	ne

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, and 2011).
[b] ne indicates parameter was not evaluated for noted end year.
[c] The percent slope change for NH_3-N is significant and decreasing but estimated as 0.00 percent change per year due to multiple ties or readings at the reporting limit.

Table 7 Trend results for routine grab data for major tributary stations to the North Bosque River. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. Significant slopes indicated at a p-value of 0.05.

		2011 Results			Slope (% change/yr)						
TCEQ (TIAER) Station	**Parameter**	**Period Evaluated**	**Kendall Test Statistic**	**p-value**	**End Year 2011**	**End Year 2010[a]**	**End Year 2009[a]**	**End Year 2008[a]**	**End Year 2007[a]**	**End Year 2006[a]**	**End Year 2005[a]**
13486 (GC100)	Conductivity	1993-2011	-0.273	0.0000	-2.0	-1.9		ne[b]	ne	ne	ne
	CHLA	1996-2011	-0.164	0.0252	-5.3	-5.0					
	E. coli	1995-2011	-0.035	0.6291					-10.9		
	NH_3-N	1993-2011	-0.216	0.0003	-2.9	-3.1	-3.0	-3.0	-5.6	-4.3	-6.8
	NO_2-N+NO_3-N	1993-2011	0.099	0.1004			4.6	4.8			9.7
	PO_4-P	1993-2011	-0.153	0.0111	-5.5	-6.1	-5.3	-7.0	-9.6	-10.4	-18.0
	TKN	1995-2011	-0.012	0.8548							
	Total-P	1995-2011	0.007	0.9164							
	TSS	1995-2011	-0.079	0.2289					-4.2		
	Total-N	1993-2011	0.078	0.2352					ne	ne	ne
11826 (NC060)	Conductivity	1996-2011	-0.051	0.3420							
	CHLA	1996-2011	-0.107	0.0618							
	E. coli	1996-2011	0.134	0.0211	4.0						
	NH_3-N	1996-2011	-0.322	0.0000	-1.5	-1.8	-1.8	-2.3	-5.2	-3.6	
	NO_2-N+NO_3-N	1996-2011	0.030	0.5790							
	PO_4-P	1996-2011	-0.291	0.0000	-1.6	-1.7	-2.5	-4.4	-5.5	-6.2	-9.7
	TKN	1996-2011	-0.055	0.2996			-3.4	-4.3	-3.7		
	Total-P	1996-2011	0.083	0.1202							
	TSS	1996-2011	0.038	0.4821							
	Total-N	1996-2011	0.033	0.5316					ne	ne	ne

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, and 2011).
[b] ne indicates parameter was not evaluated for noted end year.

Table 8 Trend results for monthly volume-weighted data for mainstem stations along the North Bosque River. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. Significant slopes indicated at a p-value of 0.05.

TCEQ (TIAER) Station	Parameter	2011 Results			Slope (% change/yr)						
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2011	End Year 2010[a]	End Year 2009[a]	End Year 2008[a]	End Year 2007[a]	End Year 2006[a]	End Year 2005[a]
17226 (BO020)	NH_3-N	1997-2011	-0.192	0.0003	-4.9%	-5.2	-5.9	-5.2			
	NO_2-N+NO_3-N	1997-2011	-0.169	0.0012	-4.8%	-4.2	-5.3	-5.9	-5.4		
	PO_4-P	1997-2011	0.042	0.4196							
	TKN	1997-2011	-0.086	0.1014		-1.4					
	Total-P	1997-2011	0.018	0.7344							
	TSS	1997-2011	0.038	0.4652							
	Total-N	1997-2011	-0.126	0.0163	-1.6%	-1.9	-2.4	-2.5	ne[b]	ne	ne
11963 (BO040)	NH_3-N	1994-2011	-0.270	0.0000	-6.5%	-7.8	-8.2	-8.0	-6.7	-5.6	-4.2
	NO_2-N+NO_3-N	1994-2011	-0.071	0.1208			-2.2	-2.5	-4.4	-4.8	-6.6
	PO_4-P	1994-2011	-0.360	0.0000	-7.6%	-7.0	-5.9	-4.3	-3.5	-2.6	
	TKN	1994-2011	-0.086	0.0598		-1.8	-2.3	-2.5	-2.2		
	Total-P	1994-2011	-0.295	0.0000	-5.2%	-4.6	-3.8	-2.9	-2.3	-1.9	
	TSS	1994-2011	0.119	0.0088	3.9%	4.4	4.0		4.1	5.4	
	Total-N	1994-2011	-0.072	0.1150		-1.3	-1.6	-1.7	ne	ne	ne
11961 (BO070)	NH_3-N	1993-2011	-0.300	0.0000	-4.5%	-4.9	-5.0	-5.3	-6.7	-4.4	-5.9
	NO_2-N+NO_3-N	1993-2011	-0.170	0.0002	-3.3%	-3.6	-3.1	-3.7			
	PO_4-P	1993-2011	-0.219	0.0000	-4.6%	-4.6	-4.4	-3.6			
	TKN	1993-2011	-0.094	0.0377	-1.5%	-2.3	-3.1	-4.0	-4.1	-2.3	-2.6
	Total-P	1993-2011	-0.171	0.0001	-3.1%	-3.0	-3.1	-3.4	-2.8		-2.5
	TSS	1993-2011	-0.007	0.8793							
	Total-N	1993-2011	-0.144	0.0014	-1.9%	-2.6	-3.0	-3.6	ne	ne	ne
11956 (BO090)	NH_3-N	1996-2011	-0.389	0.0000	-5.1%	-5.5	-6.0	-6.2	-5.9	-4.2	-5.1
	NO_2-N+NO_3-N	1996-2011	-0.114	0.0177	-2.5%	-4.3	-4.2	-3.5	-4.9	-5.8	-7.2
	PO_4-P	1996-2011	-0.132	0.0063	-2.4%	-3.2	-4.2	-4.4	-5.3	-5.2	-9.0
	TKN	1996-2011	-0.099	0.0406	-1.8%	-3.6	-5.3	-5.4	-5.4	-3.6	-3.7
	Total-P	1996-2011	-0.025	0.6014							-4.1
	TSS	1996-2011	-0.056	0.2474							
	Total-N	1996-2011	-0.188	0.0001	-2.8%	-4.4	-5.3	-5.4	ne	ne	ne

TCEQ (TIAER) Station	Parameter	2011 Results			Slope (% change/yr)						
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2011	End Year 2010[a]	End Year 2009[a]	End Year 2008[a]	End Year 2007[a]	End Year 2006[a]	End Year 2005[a]
11954 (BO095)	NH_3-N	1996-2011	-0.307	0.0000	-4.2%	-5.2	-5.8	-6.0	-8.0	-6.5	-8.2
	NO_2-N+NO_3-N	1996-2011	-0.057	0.2359					-4.3	-5.4	
	PO_4-P	1996-2011	-0.298	0.0000	-5.5%	-6.5	-6.7	-7.6	-7.9	-8.6	-11.4
	TKN	1996-2011	-0.160	0.0009	-3.0%	-4.3	-5.5	-6.7	-6.6	-4.1	-7.2
	Total-P	1996-2011	-0.163	0.0007	-2.6%	-3.2	-3.4	-4.0	-4.1	-4.9	-7.4
	TSS	1996-2011	-0.150	0.0019	-5.5%	-6.5	-6.7	-8.6	-9.0	-7.4	-11.4
	Total-N	1996-2011	-0.114	0.0180	-1.5%	-2.2	-3.0	-3.2	ne	ne	ne

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, and 2011).
[b] ne indicates parameter was not evaluated for noted end year.

Table 9 Trend results for monthly volume-weighted data for major tributary stations to the North Bosque River. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. The p-value indicates probability of significance. Significant slopes indicated at a p-value of 0.05.

TCEQ (TIAER) Station	Parameter	2011 Results			Slope (% change/yr)						
		Period Evaluated	Kendall Test Statistic	p-value	End Year 2011	End Year 2010[a]	End Year 2009[a]	End Year 2008[a]	End Year 2007[a]	End Year 2006[a]	End Year 2005[a]
13486 (GC100)	NH_3-N	1993-2011	-0.118	0.0338	-2.1	-2.3	-2.9	-2.9	-7.4		-6.4
	NO_2-N+NO_3-N	1993-2011	0.154	0.0057	4.5	4.2	5.5	5.9			
	PO_4-P	1993-2011	-0.076	0.1728				-4.2	-9.2	-9.2	-12.0
	TKN	1993-2011	0.087	0.1249					-2.9		
	Total-P	1993-2011	0.080	0.1598					-4.4		-6.5
	TSS	1993-2011	0.110	0.0528							
	Total-N	1993-2011	0.233	0.0000	4.1	3.8	3.5	3.1	ne[b]	ne	ne
11826 (NC060)	NH_3-N	1996-2011	-0.370	0.0000	-3.0	-3.1	-3.5	-3.7	-6.6	-5.2	-5.2
	NO_2-N+NO_3-N	1996-2011	-0.020	0.7015							
	PO_4-P	1996-2011	-0.284	0.0000	-3.1	-3.8	-5.4	-6.8	-7.7	-8.6	-10.7
	TKN	1996-2011	-0.049	0.3538			-3.1	-4.4	-3.8		
	Total-P	1996-2011	0.006	0.9147							-2.9
	TSS	1996-2011	0.001	0.9798							
	Total-N	1996-2011	0.012	0.8161					ne	ne	ne

[a] Summary of significant trend slopes from McFarland and Millican (2006, 2007, 2008, 2009, 2010, and 2011).
[b] ne indicates parameter was not evaluated for noted end year.

Evaluation of Stream Water Quality Goal Attainment

To measure success in improvements in water quality, the I-Plan outlines comparing average annual SRP concentrations at each of the five index stations to regression analyses of historical nutrient concentration and flow data (TCEQ and TSSWCB, 2002). A set of regression equations was derived from historical data for 1996 through 2000 representing each of the five index stations. These regression equations relate annual average concentrations of SRP from routine grab samples (y-axis values) to the base-10 logarithm of annual average stream flow (x-axis values). The index stations were not specifically defined as sampling stations in the I-Plan, but represent general locations defined from the TMDL modeling effort. The regression equations in the I-Plan were developed using data from the following stations:

- Station 17226 (BO020) for the index station above Stephenville
- Station 11963 (BO040) for the index station below Stephenville
- Station 11958 (BO085) for the index station above Meridian
- Station 11956 (BO090) for the index station at Clifton
- Station 17605 (BO100) combined with data from station BO095 for the index station at Valley Mills

Station 11961 (BO070) is also included below for comparison as a station located between 11963 (BO040) and 11958 (BO085).

Monitoring at station 11958 (BO085) was discontinued in February 2005, and data from station 18003 (BO083) were used in its place. Station 18003 (BO083) is considered more representative of the index station defined in the I-Plan as above Meridian. Flow was not measured at either 11958 (BO085) or 18003 (BO083) on a continuous basis, so annual average flow from station 11956 (BO090) was used in the equations presented in the I-Plan and in the current evaluation.

The regression equations used for the most recent comparisons of PO_4-P concentrations versus annual average flow as shown in Figures 3-8 differ somewhat from those presented in the I-Plan and early annual reports for a couple of reasons. First, annual average flows were revised based on the most updated rating curve and stage data information. Also, grab samples used in the analysis were scrutinized to make sure samples were representative of routine monitoring with relatively equal time intervals between samples throughout the year as suggested in the I-Plan (TCEQ and TSSWCB, 2002).

By including only samples representative of relatively equal time intervals, several samples were dropped that had been included in previous analyses. Previously all available PO_4-P data for grab samples had been included regardless of the time interval between samples. Using samples separated by relatively equal time intervals decreases the bias that may occur if sampling was more frequent during a particular time of year.

Extended periods of pooling or no flow in association with the relatively dry summer months still caused unequal sampling intervals in some years that could not be avoided. This was most apparent at 17226 (BO020), the most upstream mainstem station.

For 2011, stations 17226 (BO020), 11963 (BO040), and 11961 (BO070) within the upper portion of the North Bosque River all indicated PO_4-P concentrations below the pre-TMDL regression lines (Figures 3-5). For station 17226 (BO020), most post-TMDL (2001-2011) concentrations of PO_4-P in comparison with flow were near or above the pre-TMDL period (1997-2000) regression line with only three years (2001, 2008, and 2011) with data below (Figure 3). At 11963 (BO040), average PO_4-P concentrations for 2004 and 2005 were on or above the pre-TMDL regression line (Figure 4), while values for 2001 through 2003 and 2006 through 2011 fell clearly below the regression line. Although not an index station, a comparison is shown for station 11961 (BO070) located near Hico, Texas for which all years but 2004 indicated PO_4-P values below the pre-TMDL regression line (Figure 5). Of note station 11961 (BO070) was the only other station besides 11963 (BO040) to show average PO_4-P concentrations in 2006 well below the pre-TMDL regression.

For 2011, stations 11958/18003 (BO085/BO083), 11956 (BO090), and 17605/11954 (BO100/BO095) along the lower portion of the North Bosque River all indicated concentrations above the pre-TMDL regression lines (Figure 6-8). At stations 11958/18003 (BO085/BO083), 11956 (BO090), and 17605/11954 (BO100/BO095), the annual average PO_4-P concentrations for 2001-2005 consistently fell below the pre-TMDL regression line (Figures 6-8). In 2006, the annual average PO_4-P concentration at these three stations was near or above the pre-TMDL regression line. In 2007 and 2008, PO_4-P concentrations were again well below the pre-TMDL regression line. For 2009, station 11958/18003 (BO085/BO083) indicated an average concentration for PO_4-P above the pre-TMDL regression line, but in 2010, the average PO_4-P concentration was again below the pre-TMDL regression line.

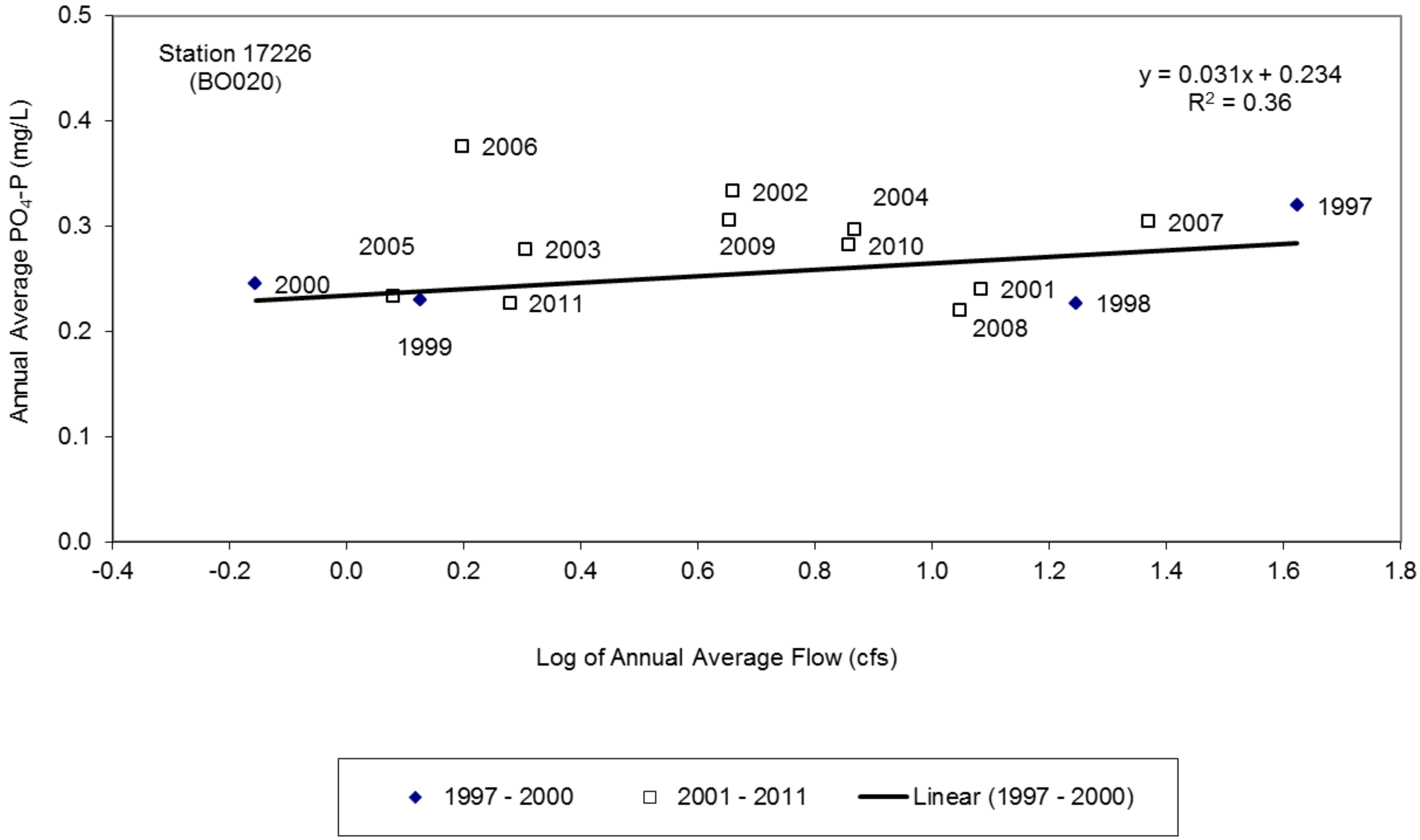

Figure 3 Relationship of the natural log of flow to annual average PO_4-P concentration of routine grab samples for station 17226 (BO020. Linear regression line fits annual average values for 2000 and before.

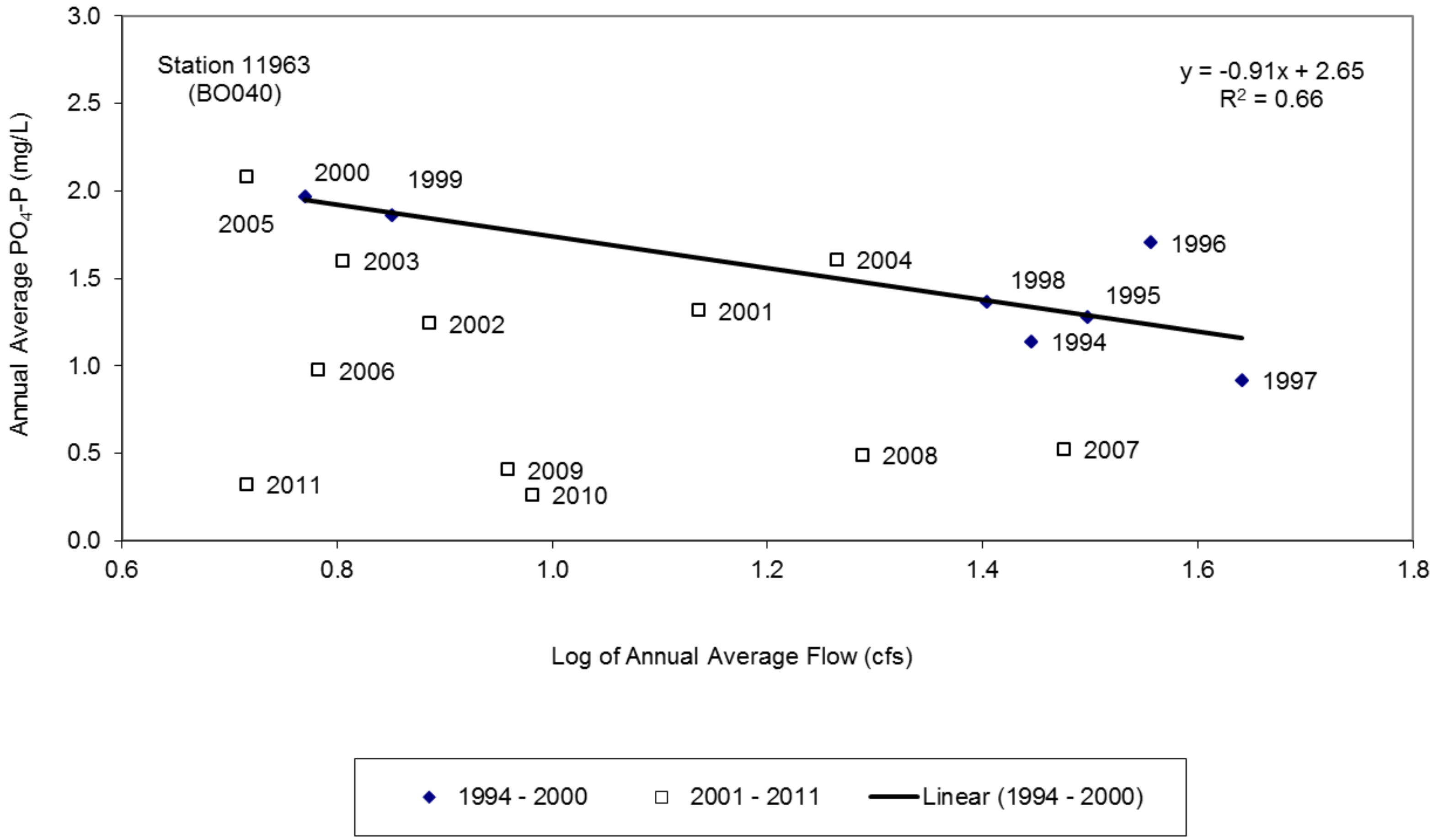

Figure 4 Relationship of the natural log of flow to annual average PO_4-P concentration of routine grab samples for station 11963 (BO040). Linear regression line fits annual average values for 2000 and before.

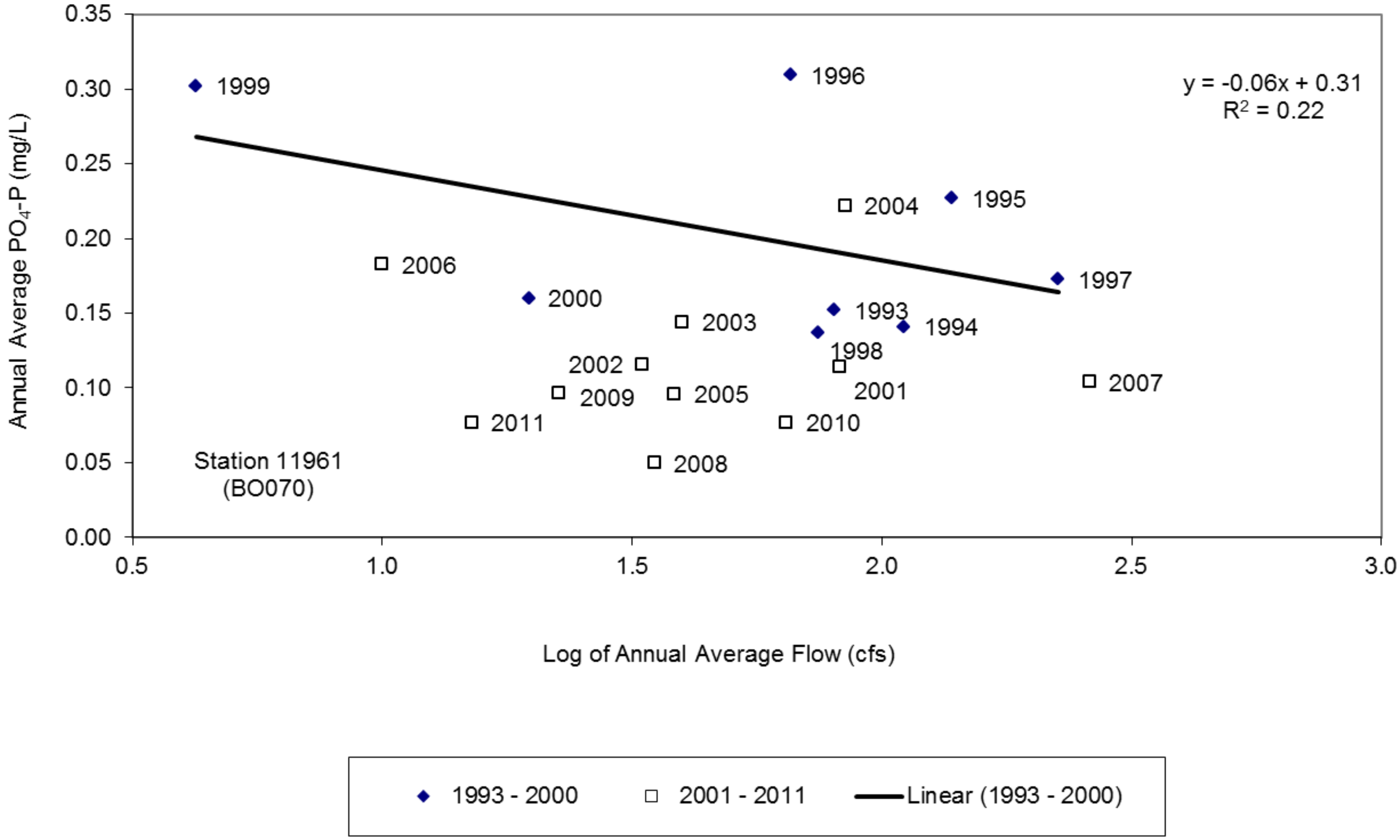

Figure 5 Relationship of the natural log of flow to annual average PO_4-P concentration of routine grab samples for station 11961 (BO070). Linear regression line fits annual average values for 2000 and before.

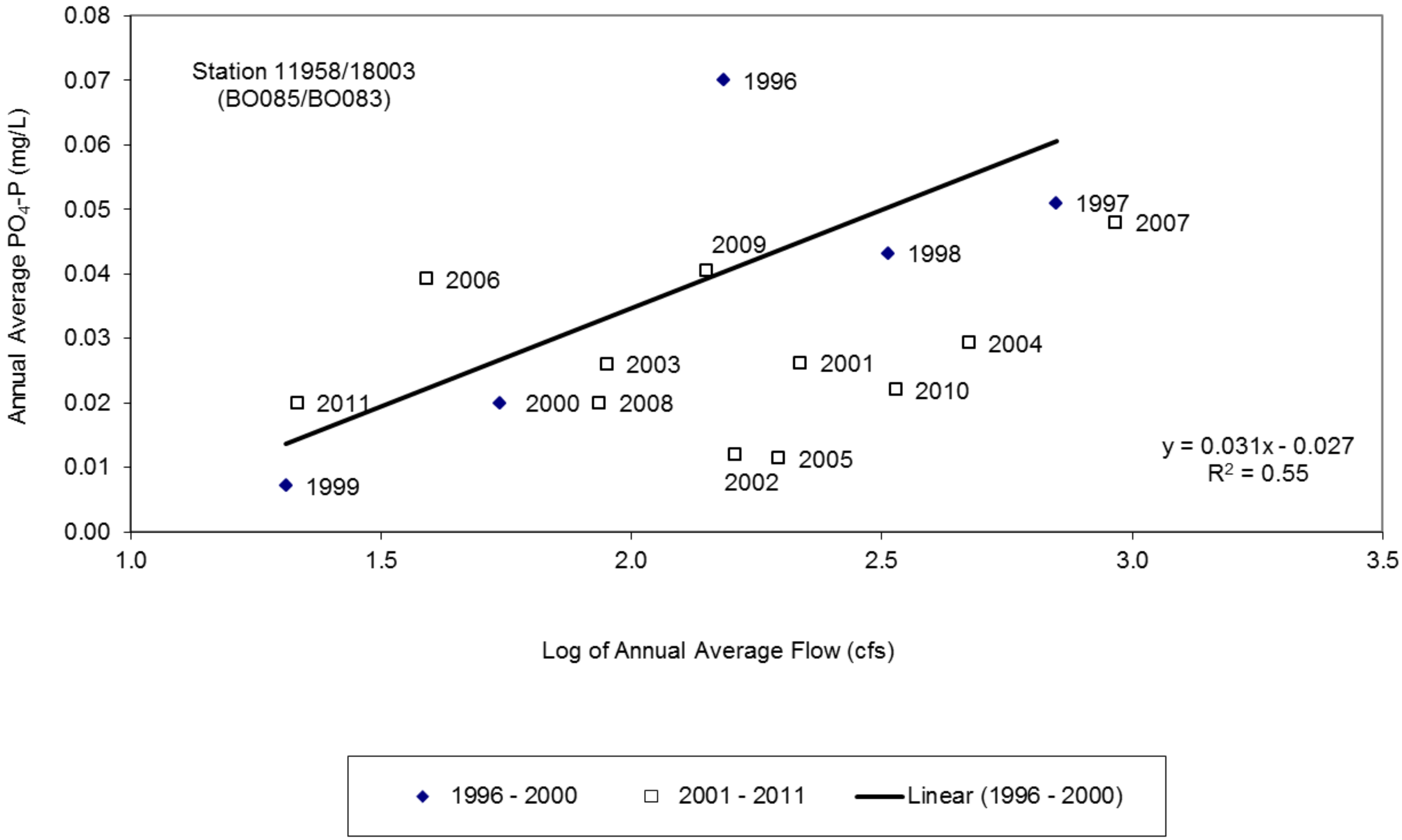

Figure 6 Relationship of the natural log of flow to annual average PO_4-P concentration of routine grab samples for station 11958/18003 (BO085/BO083). Linear regression line fits annual average values for 2000 and before.

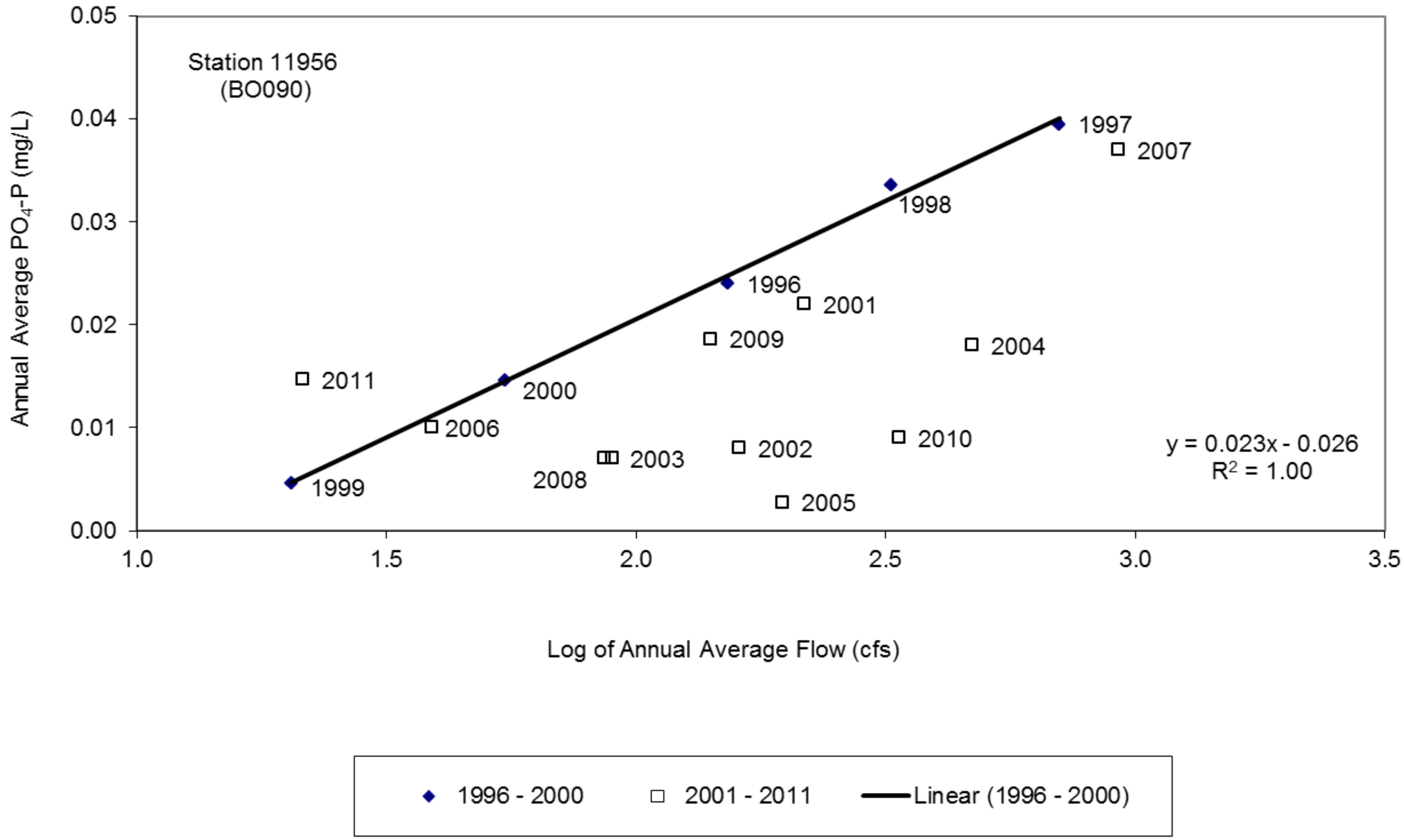

Figure 7 Relationship of the natural log of flow to annual average PO_4-P concentration of routine grab samples for station 11956 (BO090). Linear regression line fits annual average values for 2000 and before.

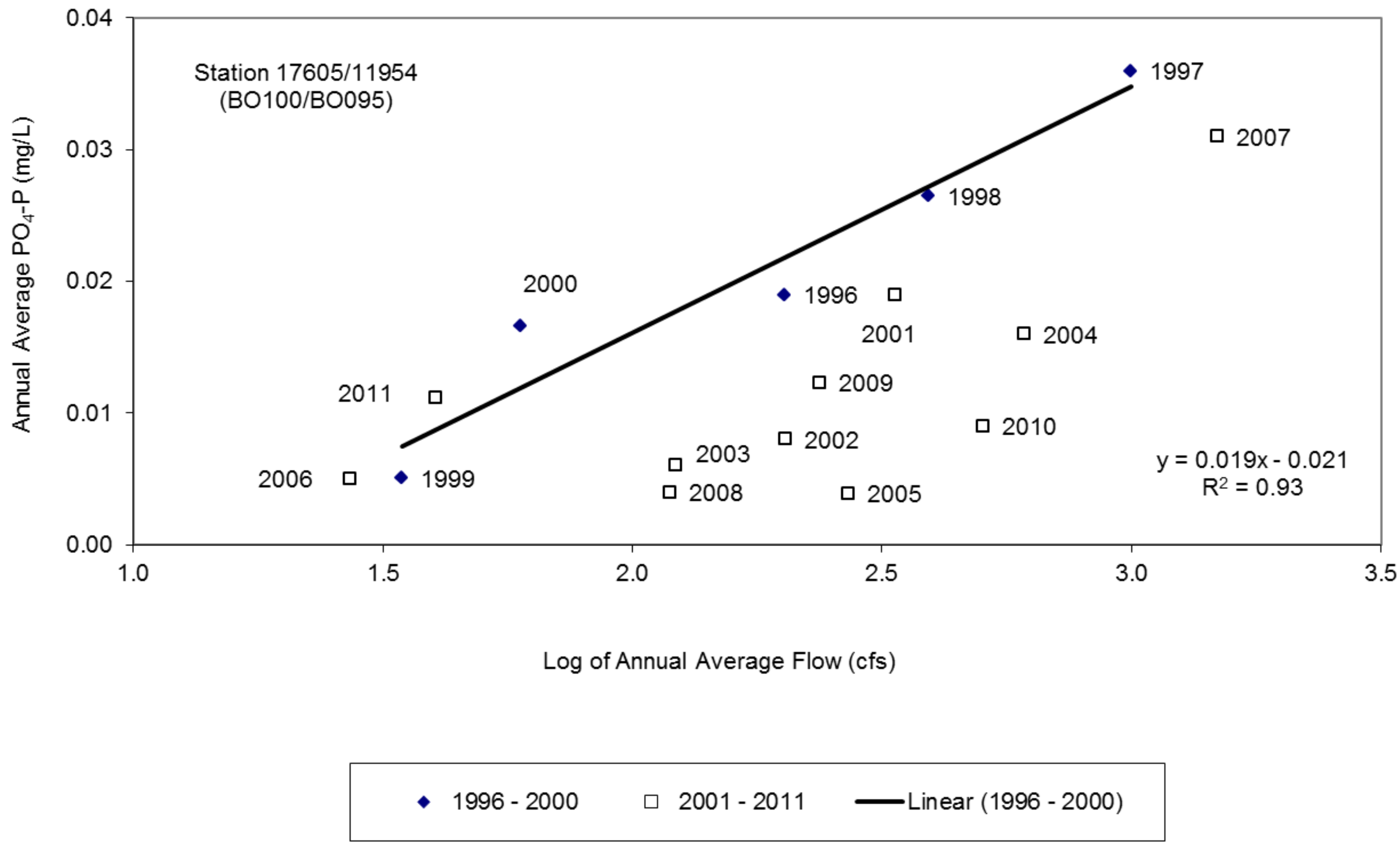

Figure 8 Relationship of the natural log of flow to annual average PO_4-P concentration of routine grab samples for station 17605/11954 (BO100/BO095). Linear regression line fits annual average values for 2000 and before.

Summary and Discussion

Results based on data through 2011 indicated several statistically significant decreasing trends in nutrients at stations within the North Bosque River watershed. In contrast, highly significant (p-value less than 0.01) increasing trends were noted at just a few sites. At 11963 (BO040), highly significant increasing trends were indicated for TSS with volume-weighted data; at station 18003 (BO083) highly significant increasing trends were indicated for CHLA with grab samples; and at station 13468 (GC100), highly significant increasing trends were indicated for NO_2-N+NO_3-N and total-N with volume-weighted data.

The increasing trend in CHLA at station 18003 (BO083) was based on data that were not flow-adjusted and that represent a relatively short time period of only nine years (2003-2011). Relatively low flow conditions in recent years may have allowed algae to concentrate at this location rather than flow through the system, as might be expected to occur under higher flow conditions.

The highest NO_2-N+NO_3-N concentrations at station 13468 (GC100) were generally associated with drier conditions and decreased flows. There were often extended periods at 13468 (GC100) during which low flow or pooled conditions occurred, which may be favoring the conversion of NH_3-N or organic-N to NO_2-N+NO_3-N at this station.

With regard to TMDLs for the North Bosque River for SRP, decreasing trends in PO_4-P were indicated along the mainstem at stations 11963 (BO040) below Stephenville, 11961 (BO070) at Hico, 11956 (BO090) near Clifton, and 11954 (BO095) near Valley Mills for routine grab and volume-weighted data. Decreasing trends in PO_4-P were also indicated for both routine grab and volume-weighted data at major tributary stations 11826 (NC060) on Neils Creek and for routine grabs at 13468 (GC100) on Green Creek. Station 11826 (NC060) is located near the confluence of Neils Creek with the North Bosque River. Neils Creek enters the North Bosque River between stations 11956 (BO090) and 11954 (BO095). Major tributary station 13486 (GC100) is located on Green Creek in the upper third of the watershed near the confluence of Green Creek with the North Bosque River. Greens Creek enters the North Bosque River about 12 river kilometers (8 river miles) above station 11961 (BO070).

These decreasing trends in PO_4-P were fairly consistent with findings in previous reports (see McFarland and Millican, 2006; 2007; 2008; 2009; 2010; and 2011). Of note, prior to the analysis of data through 2008, station 11961 (BO070) had not indicated significant decreasing trends in PO_4-P. Also prior to analysis through 2007, station 11963 (BO040) had not indicated significant decreases in PO_4-P for grab sample data. Implementation of phosphorus control at the Stephenville WWTP in late 2005 appears to be directly related to the decreasing trends in PO_4-P noted at station 11963 (BO040) and is probably influencing the decreasing trends now noted at station 11961 (BO070) further downstream (Tables 5 and 8). Box and whisker plots of monthly average concentrations by year at station 11963 (BO040) showed a notable decrease in median PO_4-P for 2006 through 2011 (Figure 9).

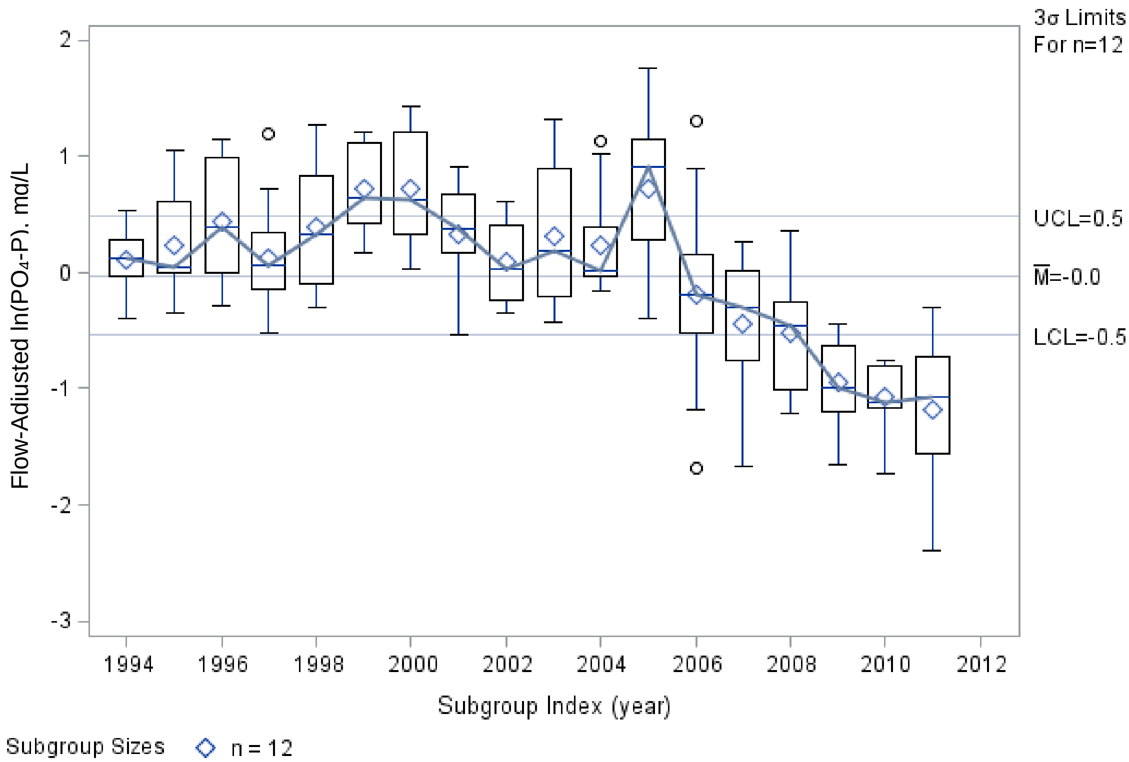

Figure 9 Annual box and whisker plots of monthly routine PO_4-P grab data for station 11963 (BO040). Data natural log transformed and flow-adjusted.

A decrease in PO_4-P concentrations also occurred at more downstream stations (11956 [BO090] and 11954 [BO095]), but the timing of the initial decrease occurred in 1999 (Figures 10 and 11), prior to implementation of phosphorus control practices at either the Stephenville or Clifton WWTPs. Of note, station 11954 (BO095) near Valley Mills is located below the discharge for the Clifton WWTP and has shown lower PO_4-P concentrations in recent years than station 11956 (BO090), which is located above the Clifton WWTP discharge.

A pattern of decreasing PO_4-P concentrations somewhat similar to those at 11956 (BO090) and 11954 (BO095) was found at station 11826 (NC060) on Neils Creek (Figure 12), which flows into the North Bosque River between 11956 (BO090) and11954 (BO095). There are indications that changes in the handling of poultry litter from operations found in the Neils Creek watershed and other drainages in the lower portion of the North Bosque watershed may have influenced these decreases in PO_4-P and other nutrient constituents.

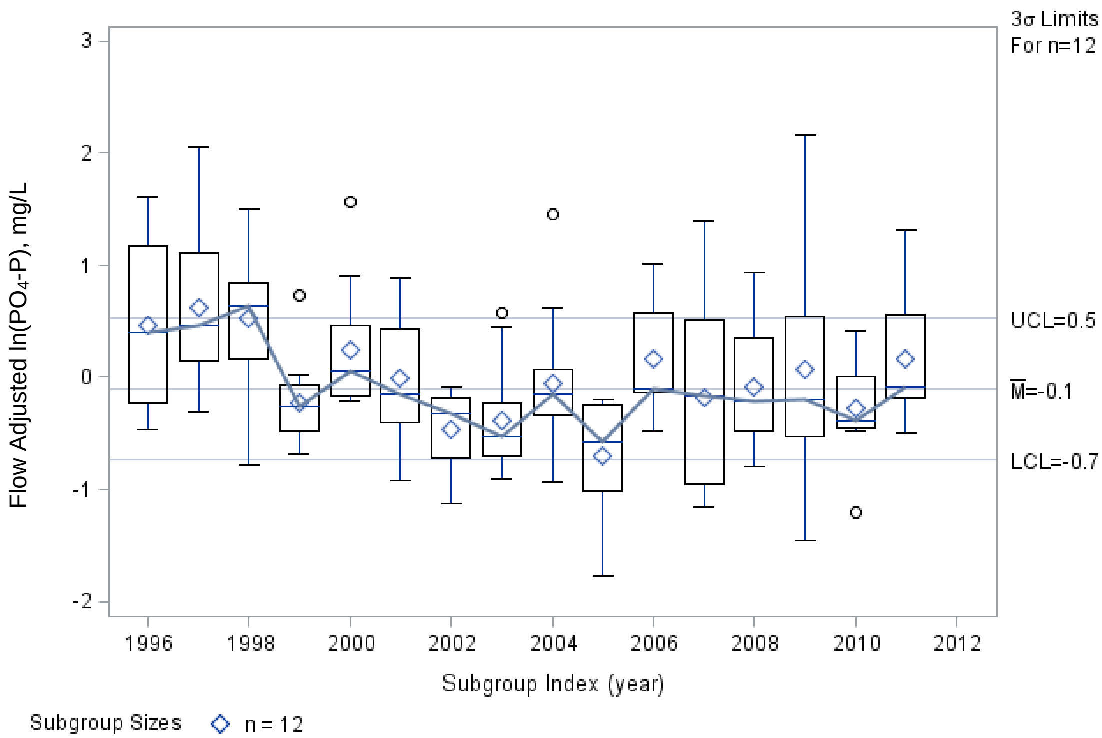

Figure 10 Annual box and whisker plots of monthly volume-weighted PO_4-P data for station 11956 (BO090). Data natural-log transformed and flow-adjusted.

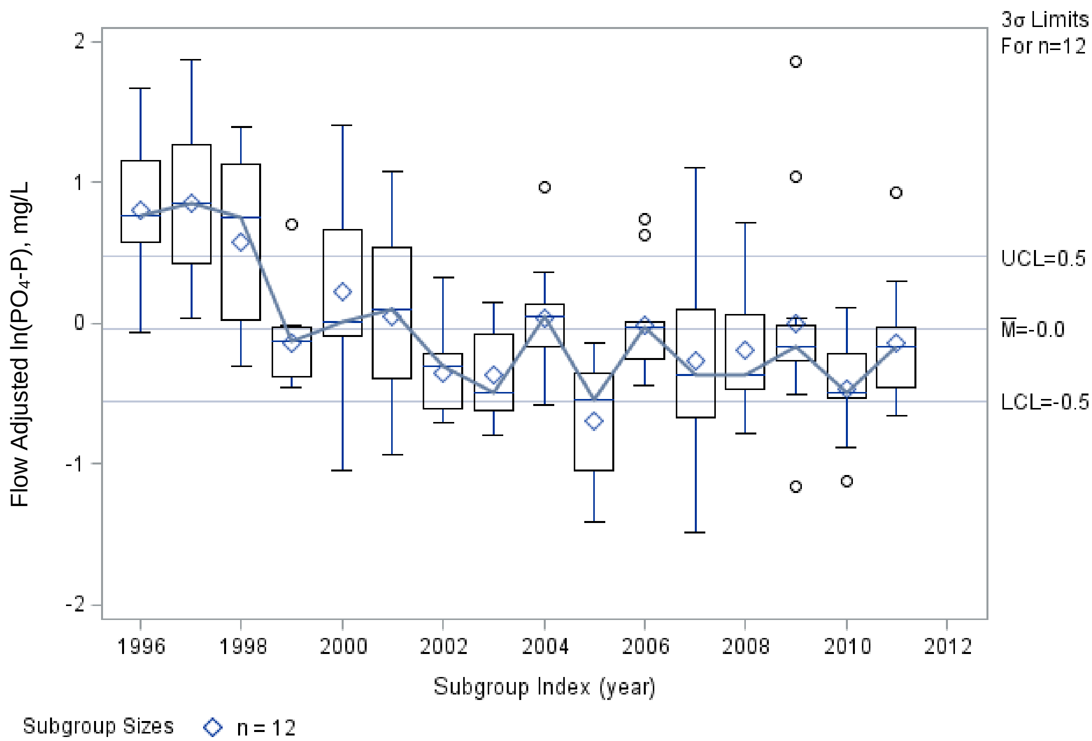

Figure 11 Annual box and whisker plots of monthly volume-weighted PO_4-P data for station 11954 (BO095). Data natural-log transformed and flow-adjusted.

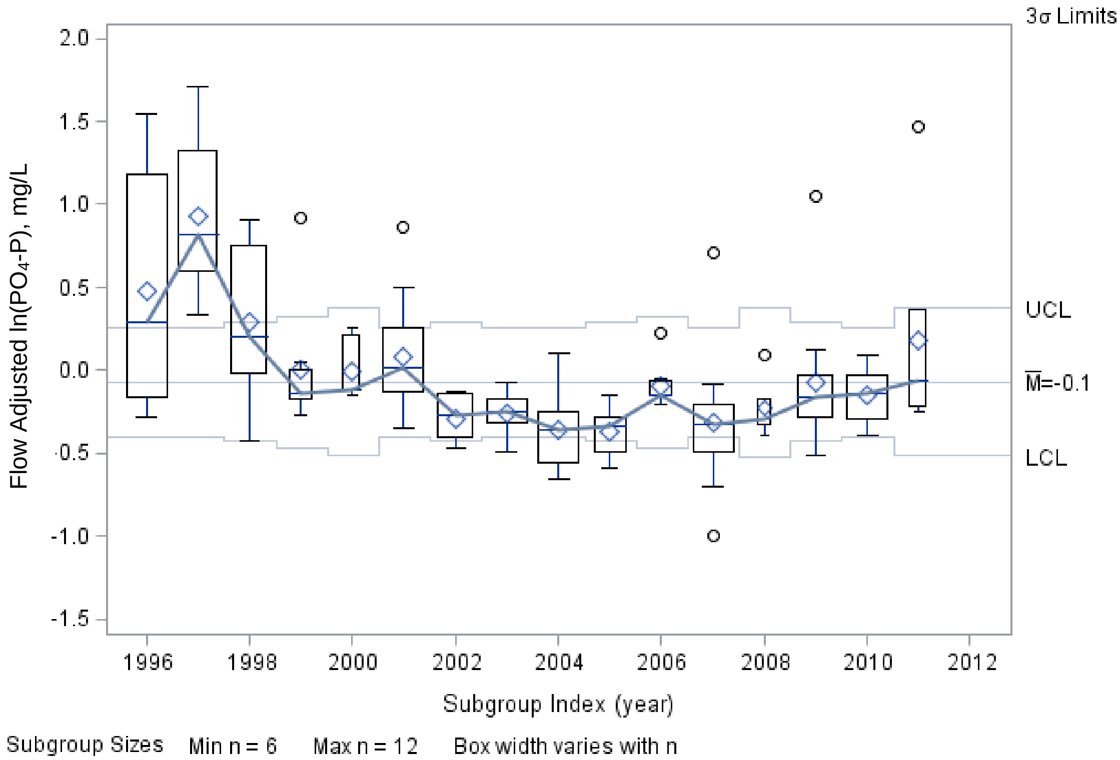

Figure 12 Annual box and whisker plots of monthly volume-weighted PO_4-P data for station 11826 (NC060). Data natural-log transformed and flow-adjusted.

As of 2006, 12 poultry facilities were known to be operating in the lower portion of the North Bosque River watershed primarily within the Meridian and Neils Creek watersheds, and these poultry operations have likely been in business since at least the early 1990s (McFarland and Jones, 2006). Based on information reported by McFarland and Jones (2006), these poultry operations have had their litter collected by a composting company (Mida-Bio) and have not conducted onsite disposal since about 2000. This initial decrease in PO_4-P concentrations at stations in the lower portion of the watershed appears to correspond in part with this change in handling of poultry litter.

In a similar fashion, changes in waste management associated with the I-Plan impacting CAFOs and AFOs are expected to impact water quality trends along the North Bosque River. Most CAFOs and AFOs are dairy operations located in the upper portion of the North Bosque River watershed. A task of this project that is still in progress is to provide updated information on land management practices on WAFs associated with CAFOs and AFOs in the watershed. Based on information from TCEQ, as of September 2011, 50 operations had permits in the North Bosque River watershed. These permits have been reviewed and a preliminary Geographic Information System (GIS) layer has been developed of the location of these facilities and associated WAFs (Figure 13). Information being tracked for WAFs includes the crop type and dominant type of waste applied (Table 10).

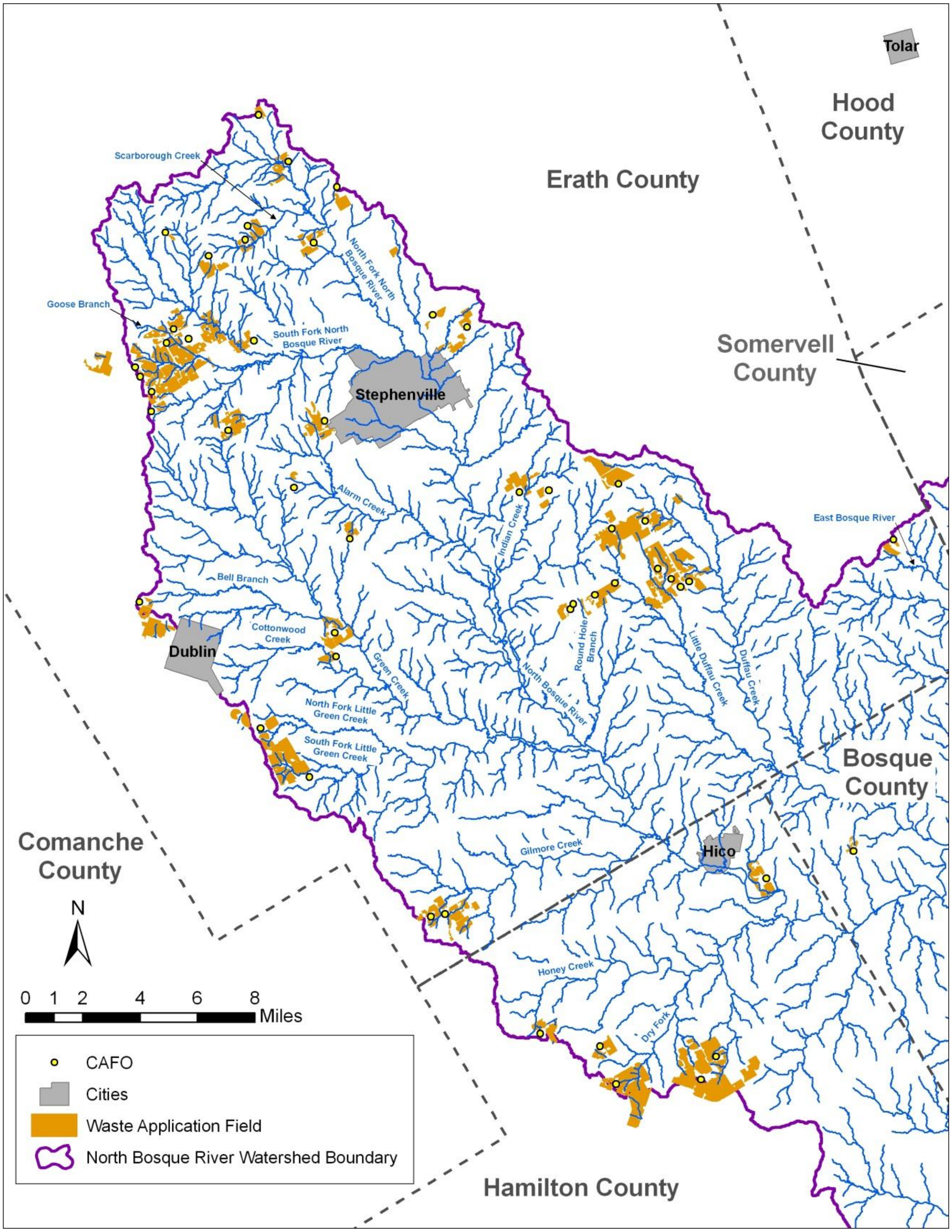

Figure 13 Provisional map of the location of CAFOs and associated WAFs within the North Bosque River watershed. Information obtained from permits and technical packets on file with TCEQ for CAFOs with active permits of September 2011.

Table 10 Provisional summary of WAF information for CAFOs with active permits in the North Bosque River watershed as of September 2011. Information obtained from permits and technical packets on file with TCEQ.

Type of Waste Applied	Crop	Acres
Both	Coastal	230
Both	Coastal/Small Grain	99
	Subtotal	328
Liquid	Coastal	2,674
Liquid	Coastal/Small Grain	3,001
Liquid	Native Grass	105
Liquid	Peanut Hay	17
Liquid	Small Grain	138
Liquid	Sorghum/Small Grain	251
	Subtotal	6,187
Solid	Coastal	2,400
Solid	Coastal/Small Grain	3,180
Solid	Native Grass	1,079
Solid	Sorghum/Small Grain	311
	Subtotal	6,969
	Total	13,484

Of note the map and WAF data presented are provisional and represent only the 50 CAFOs with permits. Unpermitted AFOs are not yet included. Once this GIS data layer is complete, a goal is to compare it with information from existing GIS data layers of land use/land cover, WAFs, and CAFO and AFO locations developed under a previous TCEQ project, *Monitoring to Support North Bosque River Model Refinement*, conducted by TIAER. These existing GIS layers are reflective of watershed conditions in early 2000s and will be used to aid in defining historical WAFs in conjunction with active WAFs. Information, such as changes in the distribution and sizes of CAFOs and AFOs and changes in the land management area used for waste application, will be used to aid in the interpretation of trend analyses.

Long-term weather patterns, particularly with regard to precipitation, can also have a notable impact on trend analyses. Precipitation and, thus, runoff have been variable over the analysis period for the watershed as indicated by annual precipitation values for Stephenville and Valley Mills (Figure 14) and stream runoff data (Figure 15). Based on precipitation data at Stephenville, most years prior to 1999 had precipitation levels near or above the 30-year average, while all but three years between 1999 and 2011 were below the 30-year average. Of note, the time history for precipitation data at Valley

Mills was not long enough to establish a 30-year average. Annual precipitation at Valley Mills followed the same general pattern between years as at Stephenville, but annual precipitation was generally greater at Valley Mills than Stephenville and indicated a larger number of years with above average precipitation using the Stephenville long-term average as a benchmark.

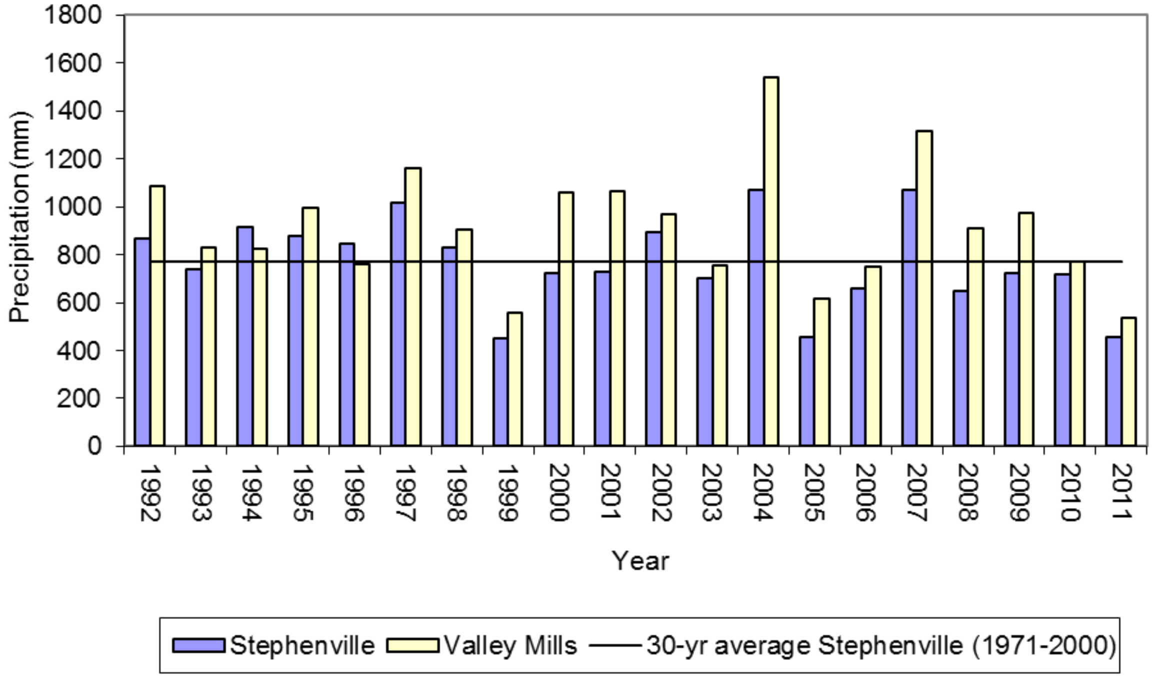

Figure 14 Temporal variability in annual precipitation at Stephenville and Valley Mills, Texas. Data source: National Weather Service (NWS) with missing values estimated from nearby rain gages maintained by TIAER or NWS.

The year 2011 was very dry with annual precipitation about 40 percent below normal with most rainfall and storm runoff occurring in May, October and December. Annual runoff in 2011 was at the lowest levels indicated over the past five years (Figure 15). Runoff amounts in 2011 were fairly comparable to runoff in 1999 and 2006, two other years with below average precipitation (Figure 14).

Comparisons of average PO_4-P concentrations for grab samples to the log of annual average flow generally supported trend analysis findings (Figures 3-8). Most post-TMDL years for stations showing significant downward trends had average PO_4-P concentrations below the pre-TMDL regression relationship. Data for 2011 indicated average PO_4-P concentrations below the pre-TMDL regression at stations 17226 (BO020), 11963 (BO040), and 11961 (BO070), and above the pre-TMDL regression at stations 18003/11958 (BO083/BO085), 11956 (BO090), and 11954/17605 (BO095/BO100).

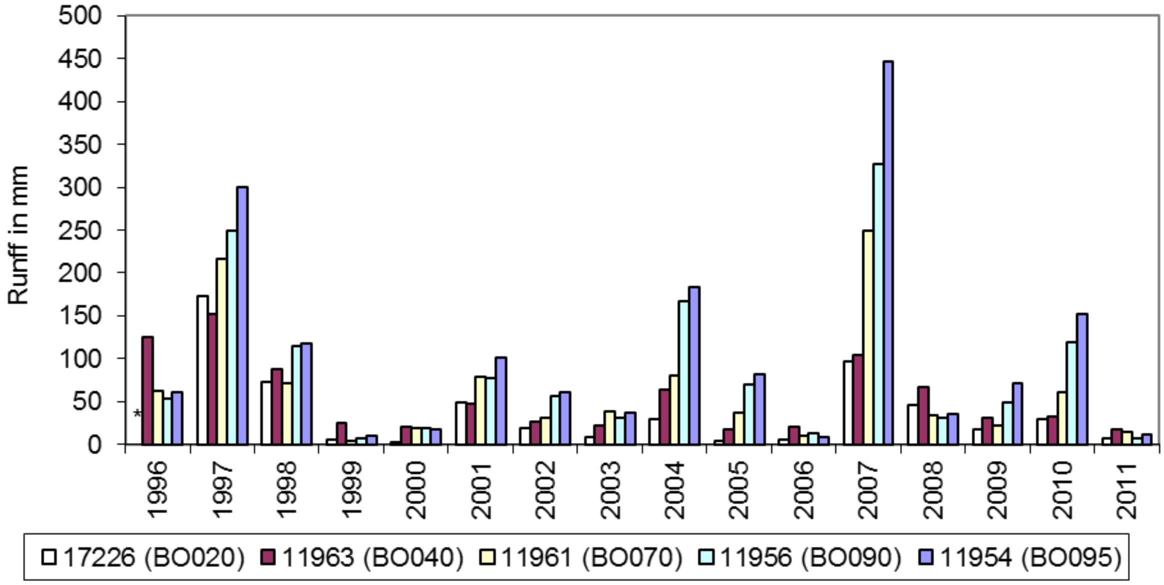

Figure 15 Annual runoff in millimeters for gauged stations along the North Bosque River. Asterisk indicates no data for 17226 (BO020) in 1996. Stations are listed in order of most upstream to most downstream.

This report presents an annual update of trends in routine grab samples and loadings for stations within the North Bosque River watershed through the calendar year 2011. Monitoring through August 2014 is sponsored under a TCEQ Nonpoint Source Program Clean Water Act 319 project in cooperation with EPA Region 6 as well as upcoming trends reports for data through 2012 and 2013.

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